**ENGINEERING EDUCATION: RESEARCH AND PROFESSIONAL SKILLS DEVELOPMENT**

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**Abstract**

Engineering education is anchored in developing skills and knowledge related to a core foundation across the areas of science and mathematics as well as engineering analysis, design and practice. However, engineering students also need to acquire research skills for successful completion of the research project in the near-term combined with enhanced professional skills for more long-term development. Therefore, this research study provides the insights gained from the delivery of a dedicated module designed to enable both research and professional skills development for masters level engineering students. The module is based on a unique combination of teaching content related to developing research skills (including the literature review process, research methods, data analysis and modelling, research ethics, research impact and relevance to sustainability) and content related to professional skills (including project management, systems engineering, engineering design, lean engineering and communication). The study includes a supporting literature review that identifies existing engineering education practices. Lessons learned and pedagogical insights are identified in regard to the design and delivery of the module, which should be of interest to those involved in the development of engineering education programs.

**Keywords**

Engineering education, research skills, professional skills, pedagogy, case study research.

# Introduction

The primary focus of engineering education is to develop the skills and knowledge related to a core foundation across the areas of science and mathematics as well as engineering analysis, design and practice (Philbin, 2020). Therefore, it is the responsibility of engineering faculty to educate students in order to become “ready to engineer”, which means they possess a deep knowledge of technical fundamentals and engineering theory as well as pre-professional engineering skills (Crawley et al., 2014). While this focus needs to be maintained, there are other emerging learning requirements, such as the need to include relevant material on sustainability; the fourth industrial revolution; relevance to employability; as well as adequate content related to the contextual application of engineering and corresponding understanding (Hadgraft & Kolmos, 2020). Furthermore, there are challenges to be addressed across engineering education in terms of improving the problem-solving and learning skills of students, developing soft skills (such as team-working, leadership and communication skills) as well as providing an understanding of enterprise related areas (Philbin, 2021), such as innovation, entrepreneurship and business management (Qamar et al., 2019). These requirements can be viewed in the context of preparing engineering students for eventual employment so they are equipped with the necessary employability skills, termed ‘transversal competencies’ (Cruz et al., 2020).

According to a more holistic perspective of engineering education, it can be observed that engineering curricula benefit from including teaching content related to conducting engineering research projects (Baekgaard & Lystbaek, 2019) and improved information literacy (Feldmann & Feldmann, 2000). This includes understanding how to conduct a literature review; design of the research methodology; and an appreciation of data analysis and other related research skills and knowledge. This understanding is required for successful completion of masters level research projects and the subsequent preparation of the thesis, or dissertation (Host et al., 2009) as well as undergraduate capstone research projects (Van Bossuyt et al., 2019). Therefore, engineering students need to acquire research skills for successful completion of the research project in the near-term combined with enhanced professional skills for more long-term development and employability prospects. This can potentially be achieved through the delivery of a dedicated engineering module (or class) that includes intra-curricular teaching material specifically designed to integrate both research and professional skills and knowledge into engineering education programs.

The structure of this article is as follows. After the introduction is the literature review relating to research and professional skills development in engineering education. This is followed by the case study investigation, which examines key aspects of the technical, research and professional skills module that is currently delivered for masters level engineering students at the university. The case study includes details on the background of the case, module structure and delivery, module assessment, and lessons learned. This is followed by conclusions and future work.

**Literature Review**

An important goal of engineering education is to prepare students for the workplace, which is influenced by the broader context, including socio-economic as well as technological drivers. Therefore, we can consider the current employment situation and planned business adaptation in response to the COVID-19 pandemic (see Exhibit 1) (World Economic Forum, 2020). As can be observed, there are a range of factors impacting employment prospects, such as the increasing digitalization of work processes. Moreover, the top skills and skill groups that employers see as rising in prominence to 2025 include the following: critical thinking and analysis; problem-solving; self-management; working with people; management and communication of activities; technology use and development; core literacies; and physical abilities. Consequently, it is crucial that strategies for engineering education take account of such a broader context as well as the associated factors and trends.

**Exhibit 1. Business adaptation in response to COVID-19 (source of data: World Economic Forum, 2020).**



The development of employability prospects for engineering students is an important requirement for undergraduate and graduate engineering programs. Such an objective requires engineering education to have an adequate focus on both engineering knowledge as well as professional skills (Philbin et al., 2019), which have been found to be interdependent and necessary to enable a deep understanding of engineering principles acquired in the context of real world engineering practice (Winberg et al., 2020). Employability is a traditional outcome sought by engineering students, which remains pivotal when engineering education programs are designed and delivered. More recently, this requirement has been augmented with a need to provide engineering students with the skills and knowledge to respond to emerging global challenges and opportunities that we currently face and this includes those associated with sustainability and the Industry 4.0 technological paradigm (Hadgraft & Kolmos, 2020). Both of these areas represent multifaceted and complex requirements, where engineering programs need to engender skills in multidisciplinary, complexity and contextual understanding. For instance, it has been recognized that there is merit in integrating the concepts and material related to sustainable development into a traditional software engineering course, including capstone projects on ‘pervasive computing and communications for sustainable development’ (Palacin-Silva et al., 2018). In other studies, problem-based learning where students work together in multidisciplinary teams to tackle a specific problem has been revealed as being effective in promoting the development of professional skills by engineering students (Ccama-Mamani et al., 2021). Moreover, project-based learning is an established approach as part of engineering education (Chen et al., 2021), where the skills required for employment can be developed through interdisciplinary experiences combined with creative thinking (Wu & Wu, 2020).

In regard to adopting a pedagogical perspective on engineering education, it has been highlighted how active, project and problem-based learning can be utilized to support the development of professional skills combined with technical expertise; indeed, the CDIO (conceive-design-implement-operate) framework has been implemented to enable such an approach, where education is focused on engineering fundamentals but are also set in the context of real-world systems and products (Campbell et al., 2009; Leslie et al., 2021). Furthermore, the CDIO approach has been shown to result in engineering students being exposed to the work environment from industry involved in product and process development combined with providing a useful tool for skills assessment (Kulkarni et al., 2020). While many researchers have investigated professional skills development for engineering students and such approaches have been adopted across many engineering programs, there can also be certain challenges with this current education trend. In the case of soft skills development (such as communication and team-working), it has been determined that for engineering education, this approach is not straightforward and such courses often receive low scores in student satisfaction surveys (Schipper & van der Stappen, 2018). While it was also found that engineering students have a positive attitude towards soft skills development, it was observed that no clear insights could be generated on what is actually causing low satisfaction scores for soft skill courses. Consequently, this represents an active area of research requiring a deeper understanding of the implications of teaching soft skills on engineering programs and the factors that contribute to a positive appreciation being exhibited by engineering students on such programs.

Research projects are an important and integral component within engineering programs and this includes both undergraduate (Almanza-Arjona et al., 2019) and graduate levels (Lino & Duarte, 2011). Preparing engineering students for research activities is therefore recommended and in this case, competence-oriented engineering education that integrates educational quality management systems with the provisions of occupational standards and employer requirements can be adopted to facilitate such a need (Gorshkova, 2017). Research projects allow technical information literacy and communication skills to be fostered and this can be achieved through engineering students conducting research assignments that require the preparation of a research report according to defined guidelines and the subsequent oral presentation of the research topic (Popescu & Popescu, 2003). Furthermore, engineering education requires the development of research and academic writing skills; this includes skills related to the dissemination of research, such as preparation of the thesis, research report and academic article (Pozzo, 2021). Engineering education should ideally be up-to-date and inclusion of the latest technological systems and knowledge in teaching content helps to ensure the relevancy of engineering programs. For instance, the smart-grid approach has been incorporated into engineering education in order to provide electrical and computer engineers with the necessary critical thinking, objectivity and ingenuity combined with research skills associated with this emerging area within electrical engineering (Ponce et al., 2021). In other studies, it has been found that emerging technologies (such as virtual reality and augmented reality for building information modelling) can be incorporated into the actual delivery of engineering education in order to improve learning for construction engineering (Wang et al., 2018). Finally, researchers have considered the digitalization of engineering education so the engineering education system can provide engineers with new digital competencies in the context of Industry 4.0 (Makarova et al., 2021).

The literature review has described some of the underlying trends in engineering education and this includes the extension of engineering programs to include both research and professional skills development. Although this trend is not without challenges and there are issues to be addressed for the benefits of such an approach to be realized. Therefore, it is useful to consider the case study of the design and delivery of a dedicated engineering module for this purpose in the next section.

**Case Study Investigation**

The research utilized the case study method (Flyvbjerg, 2011), which was selected to reveal the required detail and information to advance the level of understanding of the case (Cousin, 2005). Furthermore, the within-case analysis approach allowed the insights to be developed as part of a structured framework that included the background as well as design, processes and lessons learned from the case (Eisenhardt, 1989).

**Background on the Case**

The case is based on the delivery of a dedicated module (or class) designed to provide research and professional skills for MSc and MEng courses in the School of Engineering at London South Bank University in the UK, and the module is called Technical, Research and Professional Skills (TRAPS). The module provides training for the skills that are necessary for successful completion of the research dissertation in engineering studies in the near future combined with professional development in the long-term future. More specifically, the module teaches how to search and gather relevant technical information; how to extract the essence from a piece of technical literature and carry out a critical review of a research paper; how to carry out engineering design and appreciate systems engineering and lean engineering; how to identify ethical considerations of research; how to identify sustainability outcomes and the wider impact of research; how to manage a project in terms of time and progress in a project environment; how to write a feasibility report; and how to give presentations and communicate research projects effectively.

The module was designed in order to be compliant with the accreditation requirements for MSc engineering degree programs administered by the Institution of Engineering and Technology (IET, 2015; IET, 2020). Consequently, the specific learning outcomes were formulated to address the following IET accreditation criteria: science and mathematics; engineering analysis; economic, legal, social, ethical and environmental context. Such accreditation and assessment of academic programs is important in engineering education so as to maintain the quality of the program and the attributes of engineering graduates (Patil & Codner, 2007). Moreover, the module was designed to provide appropriate teaching content and learning associated with higher-order skills, which require a deeper learning and corresponding greater degree of cognitive processing. The higher-order skills have been depicted in ‘*Bloom’s Taxonomy’* of cognitive learning objectives and includes skills in synthesis and evaluation. These skills build on others in the taxonomy, which are knowledge, comprehension, application and analysis skills (Bloom, 1956; Adams, 2015).

**Module Structure and Delivery**

The module is delivered over 13 weeks as part of a full semester in the academic year. This includes lectures and combined tutorial sessions for weeks 1-10, followed by student presentations in weeks 11-12 and feedback is provided to students in week 13. The module’s overall aim is to ensure that engineering students from MSc and final year MEng courses undertake research and project work in both a professional and ethical manner, and are able to effectively communicate research proposals. Additionally, students are provided with support to enhance their technical and analytical background across a range of areas related to the professional engineering discipline, including project management, risk management, sustainability, engineering design, systems engineering and lean engineering. Consequently, the lectures include engineering content and theory across these areas, which provides students with the necessary background to enable the planning for their masters level research project. Exhibit 2 provides details on the main components of the module and the content covered in the lectures.

**Exhibit 2. Main components covered in the module focused on research and professional skills development.**



In the case of the most recent offering of the module, a new session was provided on professional skills development that was delivered by a team of external representatives from an industrial company. This approach was particularly successful in providing real-world experience as well as industrial context to the class, and the students were keen to understand the intricacies of being an engineer working in an industrial company. Furthermore, support on the development of information literacy is provided through the provision of materials from the university library services (such as videos and documentation on literature searching through relevant databases as well as procedures for referencing and citations) to ensure students have access to the required information technology (IT) skills for the module. For useful background on the role of academic library services in providing capabilities to build information literacy as well as supporting concepts, such as the information processing paradigm and the cognitive sciences approach, see the work of Marcum (2002).

The module includes a unique selection of teaching areas that have been included to address the requirement of building research and professional skills while also broadening the understanding and appreciation of engineering applications. For instance, the lecture session on research impact and sustainability includes underpinning material across the two areas so that students can understand the relevance of research as well as the potential linkage to the important area of sustainability (see Exhibit 3). In this case, learning is reinformed through an accompanying tutorial session relating to the impact of micro-plastics on pollution levels in the context of the UN Sustainable Development Goals (Walker, 2021).

**Exhibit 3. Contents of the lecture and tutorial session focused on research impact and sustainability.**

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| **Lecture and tutorial session on research impact and sustainability** |
| (1). Understanding research impact | * Importance of academic research
* Types of research impact
* Measuring research impact
* Research outputs, bibliometrics and altmetrics
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| (2). Introduction to sustainability | * Sustainability and sustainable development
* The triple bottom line, i.e. social, environmental and economic dimensions
* The Sustainable Development Goals (SDGs)
* Circular economy and industrial cases
 |
| (3). Tutorial session | The tutorial is focused on sustainability and specifically the case of plastic pollution in marine, freshwater, and terrestrial ecosystems globally, which has become one of the most pressing environmental issues to be addressed. Students are required to work in teams to formulate responses to the following questions:1. How do plastics currently impact achievement of the SDGs? For at least six of the SDGs, try to identify a possible area of impact.
2. Identify a research project designed to address one of the areas, including three research objectives for the research project.
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This approach allows students to gain an understanding of the potential impact of research, which is the measurable contribution that research has on society and the economy, including industrial applications (Greenhalgh et al., 2016). Further examples of research impact include cases where research has resulted in a new system or procedure adopted in a government agency or healthcare setting; research that has led to the transfer of technology from a university to a spin-out company or third party company via a licensing agreement; or the case where research has resulted in implementation of new policies to mitigate the impact of climate change and reduce greenhouse gas emissions. In addition to research impact, the lecture session has a specific focus on sustainable development, which has been defined as *“development that meets the needs of the present without compromising the ability of future generations to meet their own needs”* (Brundtland, 1987). Furthermore, related concepts such as the triple bottom line (TBL) of sustainable development (Elkington, 1998) according to social, environmental and economic performance are introduced. This understanding of the TBL is then formatively assessed through a short exercise, which is based on considering the impact on the local area in terms of social, environmental and economic outcomes for a new factory that will be producing automotive machine parts, such as gear trains, chain drives, cam systems, brakes and clutches.

A key feature of the module relates to how the research and professional skills development is anchored in technology areas and engineering applications so as to maximize the utility of the teaching material for engineering programs. This is achieved through in-class exercises and tutorial sessions (formative assessment) that are integrated with the lectures and follow-on as apart of the same overall session. An example of such an approach is a tutorial on research design and methods (see Exhibit 4). In this task, students are provided with an engineering application related to the aerospace sector. They are then required to apply the knowledge gained in the corresponding lecture on research methods in order to formulate a research method to meet the two differing requirements; where one is related to a quantitative (i.e. deductive) approach based on a traditional laboratory experiment and the other relates to a more qualitative (i.e. inductive) approach to capture the expert opinions of the subjects. Furthermore, the tutorial allows the students to demonstrate their knowledge of the dependent and independent variables involved in each research method and they also consider the internal validity of each method, i.e. the extent to which the evidence from a research study explains the cause-and-effect relationship that is under investigation (Slack & Draugalis Jr, 2001).

**Exhibit 4. Example of a class tutorial focused on research design, variables and internal validity.**

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| **Class tutorial on research design and methods** |
| Background on the case in the tutorial | * An aerospace manufacturing company would like to understand how it can implement 3D-printing technology for the assembly of landing gear components.
* There is a need to consider whether this technology could produce parts with the required tensile strength (a) and also understand the views of airlines on the use of the new manufacturing process (b).
 |
| Tutorial questions for students | (1). Identify the research question and design a research project to investigate requirement (a). Comment on the variables and the internal validity.(2). Identify the research question and design a research project to investigate requirement (b). Comment on the variables and the internal validity. |

Learning in the module is principally driven through the lectures that are integrated with the tutorial sessions (allowing formative assessment) and are assessed through the coursework (allowing summative assessment). Furthermore, the module includes a weekly reading exercise. Each week there is a reading exercise provided at the end of the lecture session, which is based on a technical article from a journal or conference proceeding and it relates to the material covered in that session. Students are provided with details of the article as well as questions or points of reflection to consider as they read the article (see Exhibit 5). This approach allows deeper reflection on the subject material over the coming week. As students engage in this task, it also provides opportunity to gain more experience of reading and evaluating research articles, which is a useful skill for the research dissertation.

**Exhibit 5. Examples of weekly reading tasks and corresponding questions/points of reflection.**

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| **Article** | **Questions/points of reflection** |
| From week # 5: ‘Data modeling versus simulation modeling in the big data era: Case study of a greenhouse control system’ by Kim et al. (2017) | 1. How does data modelling differ to simulation modelling?
2. How is the proposed modelling framework used in the two applications?
3. What are the key features of the data modelling approach that is used in the paper?
 |
| From week # 7: ‘Six transformations to achieve the sustainable development goals’ by Sachs et al. (2019) | 1. What are the six transformations proposed by the authors?
2. How can the transformations be implemented?
3. Why can’t the transformation be designed and imposed from the top down?
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**Module Assessment**

The module is primarily assessed through coursework and is based on summative assessment to evaluate students learning and understanding of the nature of research and technical processes as well as professional skills in the area of engineering. This is based on carrying out a feasibility study of the proposed masters level research project, which is to be undertaken in the following semester. The coursework is composed of two main components, which are summarized as follows:

* *Assignment report* (assessing research and professional skills): This component is assessed through a formal report covering the feasibility study of the proposed research project. The component constitutes 70% of the final mark for the module.
* *Presentation* (assessing technical and presentation skills): This component is assessed through a presentation covering the topic of the feasibility study of the proposed research project. The component constitutes 30% of the final mark for the module.

The requirement for the feasibility study is to assess the viability of the proposed research project. This provides transferrable skills since engineers are typically required to provide feasibility study reports to support the development of engineering projects. The feasibility study should provide analysis of the objectives, requirements and system concepts for the engineering research project. It is envisaged that the report should assess a number of aspects of the research project, including technology and engineering theory considerations; research methodology considerations; project and risk considerations; ethical considerations; wider research impact and potential sustainability considerations; and any other relevant considerations. The presentation is based on a short summary of the assignment report and allows demonstration of verbal communication skills. Overall the coursework (including report and presentation) is required to assess achievement of learning outcomes across the areas of science and mathematics; engineering analysis; and the economic, legal, social, ethical and environmental context of the research.

The summative assessment described above complements the formative assessment provided throughout the module via the in-class exercises and more detailed tutorial sessions. Both the exercises and tutorials are required to reinforce learning from the respective lecture session, while having an additional focus on highlighting technology and engineering applications for the research and professional skills and knowledge. For a concise treatment and accompanying theoretical reflections on formative and summative assessment see the work of Taras (2005).

**Lessons Learned from the Case**

A number of lessons learned and insights from the study have been identified, which are as follows:

1. Employability skills and knowledge of engineering students can be enhanced through the provision of intra-curricular teaching content specifically designed to develop professional skills in areas such as communication (written and oral), team working, project management and ethical standards for engineers.
2. Research skills and knowledge of engineering students can be developed through project-based learning, where students undertake a feasibility study of the proposed research project. This approach allows detailed planning in areas such as ideation and definition of research scope, literature review, research methods, data collection and analysis.
3. When delivering teaching content related to research and professional skills for engineering students, it is important to ensure the material is relevant and interesting. This can be achieved through inclusion of examples, exercises and tutorial sessions based on technology-based applications, engineering theory and industrial applications.
4. In order to ensure engineering education is up-to-date, contemporary areas of subject matter can be included, such as sustainability as well as digital technologies associated with Industry 4.0 and digital transformation (such as the internet-of-things, augmented reality and artificial intelligence). The inclusion of such content also increases the level of interest from students in the teaching material since it is topical in nature and relevant to the challenges and opportunities for engineers in modern society.
5. Achievement of learning outcomes can be supported through integrating tutorial sessions that follow-on directly from the lecture, where the knowledge and understanding developed in the lecture can be demonstrated through the tutorial task. Moreover, didactic delivery of the lecture can be augmented through the team-based work in the tutorials where the lecturer is in more of a facilitating and guiding role.
6. It is important when developing research skills as well as professional skills that students are able to acquire a suitable level of information literacy in regard to using information technology (IT) tools to plan the proposed research project. Where possible, information literacy can be developed through suitable exercises as well as the provision of guidance and support from academic library services at the university.
7. The inclusion of a weekly reading task provides a broader coverage of the engineering subject area and allows students to develop experience of engaging with academic literature. This approach reinforces learning of the overall approach for engineering research through in-class discussions held on the article.
8. It is important to monitor and evaluate the learning of students according to pre-defined learning outcomes and this can be supported through an integrated assessment framework that includes both formative assessment (in-class exercises and tutorials) combined with summative assessment (coursework based on preparation of the assignment report accompanied by presentation of the report highlights).

# Conclusions and Future Work

Engineers are faced with greater levels of technology uncertainty and complexity as part of the current dynamic and competitive industrial environment. In this context, engineering education continues to evolve and respond to both the challenges and opportunities facing academic programs. Such changes should be guided by research on expertise and the learning processes involved in engineering education. While continued development of numerical and science-based knowledge associated with engineering theory as well as the practical application of engineering remains pivotal, engineering education should also seek to develop employability prospects for graduating students. Such employability can be enhanced through gaining professional skills, such as those associated with communication and project management. Additionally, engineering students often need to complete a substantial research project or contribute to a team-based capstone project and therefore the development of research skills is an important requirement for engineering programs. Consequently, delivery of a dedicated module (or class) that focuses on the development of both research and professional skills addresses these requirements and also helps to improve student outcomes on engineering education programs as well as enhancing long-term career prospects.

This research study investigated the need for research and professional skills development in engineering education through a supporting literature review and case study of the technical, research and professional skills module delivered for masters’ level engineering students. The case study involved gathering background on the module and reflection on the design and structuring of the module as well as module assessment and formulation of a set of lessons learned from the delivery of the module over the last several years. In regard to employability, the module provides students with skills in planning, execution and communication of an engineering project and utilization of methods for analyzing results and preparing reports as well as the dissemination of the results through report writing and presenting. Additional skills and knowledge related to professional engineering practice are provided and these skills are desirable for graduate level employment opportunities. In addition to professional skills development, the module includes a clear focus on the development of research skills and this is underpinned by the formative and summative assessment, where the latter is based on the preparation of a feasibility study report (and presentation) for the proposed research project. The module includes fundamental aspects associated with designing a research project (such as carrying out the literature review, understanding research ethics, developing the research method and data analysis) combined with other broader considerations (such as understanding the potential for research impact and link to sustainability). This approach is augmented with the teaching content being highly focused towards engineering applications based on different areas of science and technology; consequently, the research and professional skills development is tailored and relevant to engineering education.

Lessons learned have been identified from the case study and this includes aspects associated with developing both research and professional skills, including various insights related to the academic structure and pedagogy of the module. The material provided in the case study should be of benefit to practitioners engaged in the development of engineering education and specifically initiatives incorporating an intra-curricular focus on research and professional skills development. The study also seeks to inform future research activities in this area.

In regard to future research work, it is recommended that further research is carried out on improving the understanding of the different approaches to developing research and professional skills and knowledge in engineering education. This can be achieved through survey-based quantitative studies of multiple academic institutions in order to derive best practice and details on different approaches. Furthermore, research is suggested on clustering the sub-skills and corresponding characteristics that constitute both research and professional skills so that an improved understanding can be developed of the optimal pathway for incorporating this provision into engineering education.

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