**BIBLIOMETRIC REVIEW OF pROFESSIONAL SKILLS DEVELOPMENT IN ENGINEERING EDUCATION: Implications for ENGINEERING MANAGEMENT PROGRAMS**

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**Abstract**

Engineering managers benefit from having professional skills in areas such as communication, teamwork, decision-making, project management, ethical awareness, and an appreciation of contemporary issues. These skills complement the technical engineering foundation in relevant areas of science and mathematics combined with a solid grounding in engineering analysis, design and practice. However, there are continuing challenges in regard to understanding the optimal approaches for integrating professional skills and knowledge development in engineering management programs and more broadly across engineering education. Therefore, this study conducted a bibliometric review on professional skills development in engineering education. The method is based on systematic searching of the extant literature, which identified 88 documents according tokeyword retrieval over a 5 year period from 2018 to 2022. The documents are categorized in terms of publication metrics (such as publication year, subject area and country of origin) followed by bibliometric analysis to determine co-occurrence of keywords, co-occurrence of text, and co-authorship in terms of countries. The study includes content analysis of the 10 publications having the highest citation count. This analysis allowed emerging trends on the publications to be identified as well as collaboration patterns, research strategies, and structure of the knowledge base. The study concludes with a set of implications for engineering management programs arising from the bibliometric review.

**Keywords**

Engineering management programs, engineering education, teaching, professional skills, bibliometric review.

# Introduction

Engineering managers need to possess the required professional skills in areas such as communication, teamwork, decision-making, project management, ethical awareness, and an appreciation of contemporary issues. Such professional skills sit alongside core engineering skills and knowledge in science and mathematics combined with a comprehensive understanding of engineering analysis, design and practice (Philbin, 2022). However, there are different perspectives on the optimal routes for the provision of professional skills development in engineering management programs and more broadly across engineering education as well as emerging opportunities to adopt new approaches for teaching and learning, such as greater use of digital technologies (Broo et al., 2022).

Adopting an engineering program accreditation perspective and in the United States, the ABET (Accreditation Board for Engineering and Technology, 2021) criteria for undergraduate engineering has recently been revised and includes the ‘Criterion 3. Student Outcomes’, which are as follows: (1). An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics; (2). An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors; (3). An ability to communicate effectively with a range of audiences; (4). An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts; (5). An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives; (6). An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions; (7). An ability to acquire and apply new knowledge as needed, using appropriate learning strategies. It can be observed that the new set of student outcomes includes technical engineering skills and knowledge developed alongside professional skills. But the problem arises when professional skills are assessed since normal examination procedures are often inadequate (Shuman et al., 2005); consequently, to address this situation, project-based learning and corresponding assessment is often advocated.

Engineering management programs at the undergraduate and graduate levels include engineering and management related topics across the scope of the engineering management discipline but in order for students on such programs to have good employability prospects and be prepared for the workplace, there is a need to develop professional skills in parallel with the engineering management provision. This requirement is common across other engineering areas, such as mechanical engineering, civil engineering, and chemical engineering programs. It is therefore logical that engineering management programs need to be designed to deliver learning outcomes to allow engineering students to engage with such wider areas of competence when working in engineering practice.

It is recognized that engineering education (including engineering management education) should target the development of a complementary set of learning experiences across conceptual, practical, and engineering project dimensions in conjunction with supporting the development of both technical and professional skills as part of an integrated program (Litzinger et al., 2011). Although studies have identified how there are compelling reasons for engineering education to undergo significant change in the context of the complex challenges of the twenty first century (Winberg et al., 2020), including the need for entrepreneurship related skills for engineering managers (Philbin, 2021). Such challenges include the requirement for engineering management graduates to be able to operate in highly competitive industrial environments; the lack of engineers both in developing and developed countries; issues of high attrition in engineering programs; as well as a lack of gender and racial diversity in engineering programs and professions. Consequently, engineering management students need to be equipped with a broader range of skills to be competent, which extend to both technical as well as professional skills (Philbin et al., 2019), including digital literacy, independent and autonomous learning, openness to criticism, assertiveness or social interaction and empathy (Caeiro-Rodríguez et al., 2021). Furthermore, effective teaching models for professional skills include problem and project-based as well as game-based approaches. Indeed, new pedagogical models are envisaged that support the development of professional skills for engineering students, which includes organization, planning, analysis, and synthesis; application of knowledge into practice; clear oral and written expression; critical and self-critical capacity; collaborative work; capacity for initiative and leadership (Forcael et al., 2021).

As summarized above, the engineering education landscape is complex both from a requirements and pedagogical perspective and this includes engineering management education. Professional skills are recognized as being an important, and integral, component of engineering education alongside technical engineering skills and knowledge. But there remain challenges in capturing the best practice for the delivery of professional skills development in engineering management education combined with specific issues in relation to teaching modes of delivery, assessment, and the ongoing suitability of engineering education. Therefore, this study applied the bibliometric review method to characterize the current status of the extant literature on professional skills development in engineering education, which is utilized to derive a set of implications for engineering management programs.

# Method

The study adopted the bibliometric review method for the investigation, which was selected to provide an exploratory analysis of the status of the extant literature focused on professional skills development in engineering education to inform best practice for engineering management programs. The bibliometric methodology incorporates the application of quantitative techniques (i.e. bibliometric analysis, such as citation analysis) on bibliometric data (e.g. units of publication and corresponding citation data) (Donthu et al., 2021). Consequently, bibliometric review is a rigorous method that can be used for exploring and analyzing large volumes of scientific publication data. The method allows researchers to identify specific trends and patterns on scholarly areas within a defined field, thereby helping to identify collaboration patterns, research strategies, and the structure of the knowledge base. Bibliometric reviews have been undertaken across a range of different applications and disciplines in order to shed light on the corresponding knowledge base, such as carbon capture and utilization in the energy sector (Nawaz et al., 2022); and supply chain management and green technologies (Yu et al., 2022). Furthermore, a recent trend has been the use of certain software that enables detailed analysis of publications. For example, VOSviewer (https://www.vosviewer.com/) can be used for the construction and visualization of bibliometric networks, which can be derived according to citation, bibliographic coupling, co-citation or co-authorship relations for a given dataset of publications. VOSviewer was developed by Nees Jan van Eck and Ludo Waltman at Leiden University's Centre for Science and Technology Studies (CWTS). For examples of recent bibliometric studies that have utilized the VOSviewer software, see the work of Yu et al. (2020) and Oladinrin et al. (2022). Therefore, the bibliometric review methodology (including visualization of network data) was selected for the exploratory analysis of professional skills development in engineering education to derive a set of implications for engineering management programs.

A search was carried out in the Scopus Abstract and Citation Database on 2nd February 2023 using the following search terms within the field of ‘Article Title, Abstract, Keywords’: “engineering education” AND “professional skills”. This identified an initial dataset of 903 publications. Stage # 1 screening extracted articles for the 5-year period of 2018-2022, which resulted in 342 publications. This was followed by stage # 2 screening to exclude conference proceedings, book chapters and other types of publications, which resulted in 89 journal article publications. This was followed by stage # 3 screening, which excluded publications in other languages, which resulted in 88 journal article publications in English. Subsequently the 88 journal articles were included for descriptive data collection on the publications followed by bibliometric analysis using VOSviewer software. Version 1.6.18 (release date: 24 January 2022) of the VOSviewer software was used in the study supported by Java, Version 1.8.0\_361 (Oracle Corporation).

Finally, 10 publications having the highest citation count were included for content analysis of the literature. Exhibit 1 provides a summary of the method for systematic searching, review and analysis employed in the study, which is consistent with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analyses) approach that underpins the SLR (systematic literature review) method (Moher, 2009).

**Exhibit 1. Method for systematic searching, review and analysis of literature employed in the study.**



# Results

The results are provided in three parts, namely the first part includes the descriptive data of the publications from the systematic searching; the second part provides the network visualization from the bibliometric analysis; and the third part provides a summary of the top ten highest cited publications selected for content analysis.

**Part (1) – Descriptive data of the publications from the systematic searching**

The first part of the bibliometric review method is to capture descriptive data on the publications and Exhibit 2 shows the number of publications per year. As can be observed, there is a steady number of publications in each year with a modest trend of an increasing number of publications from 2018 (N=13) to 2022 (N=22). Although this trend is not significant and the pattern of publications each year potentially indicates a mature field of study.

**Exhibit 2. Number of publications over the 5-year period of the study (2018-2022).**



In terms of geographical location of the article authors, Exhibit 3 provides a breakdown of the author countries (with countries having at least 3 authors). This identifies the country with the most number of publications is USA (N=21), followed by China (N=12) and the UK (N=10). This is followed by a range of other countries, including Spain, India, Canada, Sweden, Australia, Brazil and Chile that have a decreasing number publications.

**Exhibit 3. Country locations of authors (with countries having at least three authors).**



In regard to the journal title, Exhibit 4 provides a breakdown of the publications (with journals having at least two publications). The top five most frequent journals having publications are as follows: *Journal of Engineering Education Transformations* (N=8), *European Journal of Engineering Education* (N=8), *International Journal of Engineering Education* (N=6), *IEEE Transactions on Education* (N=6), and *Advances in Engineering Education* (N=5). There were also a further 2 journals having four publications each (N=8); 2 journals having three publications each (N=6); 8 journals each having two publications each (N=16); and 25 journals each having a single publication (N=25). The descriptive data also includes the frequency of subject areas for the 88 publications and is provided in Exhibit 5. This includes the following results: engineering education (N=70); students (N=51); professional skills (N=46); professional aspects (N=26); teaching (N=14); curricula (N=13); surveys (N=9); engineers (N=8); problem based learning (N=7); and education (N=6). It should be noted that the number of publications across all the subject area does not total 88 since a given publication can be associated with more than one subject area.

**Exhibit 4. Frequency of publications in journal titles (with journals having at least two publications).**



**Exhibit 5. Frequency of subject areas for the publications.**



**Part (2) – Network data from bibliometric analysis**

The second part of the bibliometric review method is to undertake network analysis on the publications to derive further information on the status of the knowledge base on professional skills development in engineering education (see Exhibits 6-8). In this regard, Exhibit 6 provides a co-occurrence map for keywords from the 88 publications, which is based on the top 44 keywords from a total dataset of 779 keywords and with a minimum number of occurrences of 3. The map includes 6 clusters of keywords: Cluster # 1 in red (N=13); cluster # 2 in green (N=11); cluster # 3 in blue (N=6); cluster # 4 in yellow (N=6); cluster # 5 in purple (N=5); and cluster # 6 in aqua (N=3). The top 10 keywords featured in this map have the following number of occurrences (O) and corresponding total link strength (TLS): engineering education (O=70, TLS=276); students (O=51, TLS=239); professional skills (O=46, TLS=198); professional aspects (O=26, TLS=139); teaching (O=14, TLS=78); curricula (O=13, TLS=72); surveys (O=9, TLS=51); problem based learning (O=7, TLS=41); engineers (O=8, TLS=36); and students (O=5, TLS=33).

**Exhibit 6. Co-occurrence map for top 44 keywords having a minimum number of occurrences of 3.**

Diagram

Description automatically generated

**Exhibit 7. Co-occurrence map for text data where 40 meet the minimum threshold of 10 occurrences.**

Diagram

Description automatically generated

**Exhibit 8.** **Network map for the author countries based on a total of 39 countries in 15 clusters.**

Chart, scatter chart

Description automatically generated

Further network analysis was possible through considering text data extracted from the ‘title’ and ‘abstract’ fields of the publications. Therefore, Exhibit 7 provides the co-occurrence map for text data derived from a total of 2810 terms across all 88 publications, where 40 meet the minimum threshold of 10 occurrences, and 24 terms are selected based on being in the 60% of the most relevant terms. The data is grouped in 3 clusters, comprising cluster # 1 in red (N=11; ability, assessment, communication, course, problem, professional skill, student, teaching, team, technology, time); cluster # 2 in green (N=9; activity, engineer, engineering student, experience, impact, need, role, set, survey) and cluster # 3 in blue (N=4; analysis, contribution, methodology, work). Exhibit 8 shows the network map for author countries. There are a total of 39 countries in 15 clusters. The top 5 clusters are cluster # 1 (N=7; Canada, France, Germany, North Macedonia, Portugal, Slovakia, United Kingdom); cluster # 2 (N=4; Estonia, Kenya, Sweden, Uganda); cluster # 3 (N=5; China, Greece, Italy, Macau (China)); cluster # 4 (N=4; Australia, Mexico; United Arab Emirates, United States); and cluster # 5 (N=4; Brazil, Chile, Peru, Spain). The remaining countries (N=16) are spread across 10 clusters; 6 of these have no network associations and are single country clusters.

**Part (3) – Publications selected for content analysis**

Exhibit 9 provides a summary of the 10 publications with highest citation count selected for content analysis. It should be noted the number of citations was generated at the time of the search and the figures are only the citations captured from the Scopus database, which may be different to citation figures obtained in different literature databases.

**Exhibit 9. Summary of the 10 highest cited publications selected for content analysis.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **No.** | **Reference** | **Article title** | **Journal title** | **Publisher** | **No. of citations** | **Article keywords** |
| 1 | Garduño-Aparicio et al. (2018) | A Multidisciplinary Industrial Robot Approach for Teaching Mechatronics-Related Courses | IEEE Transactions on Education | IEEE | 57 | Educational robots, education, servomotors, service robots, prototypes, microcontrollers |
| 2 | Sánchez Carracedo et al. (2018) | Competency maps: An effective model to integrate professional competencies across a STEM curriculum | Journal of Science Education and Technology | Springer | 36 | STEM education, engineering education, professional competencies, professional skills, academic programs, curriculum design, competency maps, competency units, learning outcomes |
| 3 | Ahmed & Opoku (2022) | Technology supported learning and pedagogy in times of crisis: The case of COVID-19 pandemic | Education and Information Technologies | Springer | 24 | Engineering education, Covid-19 pandemic, online teaching & learning, emergency response |
| 4 | Jesiek et al. (2018) | Boundary spanning and engineering: A qualitative systematic review | Journal of Engineering Education | Wiley | 24 | Competence, professional skills, synthesis, systematic review |
| 5 | McFaul & FitzGerald (2020) | A realist evaluation of student use of a virtual reality smartphone application in undergraduate legal education | British Journal of Educational Technology | British Educational Research Association | 23 | None listed |
| 6 | ElZomor et al. (2018) | Leveraging vertically integrated courses and problem-based learning to improve students’ performance and skills | Journal of Professional Issues in Engineering Education and Practice | American Society of Civil Engineers | 21 | None listed |
| 7 | Noel et al. (2018) | Exploring collaborative writing of user stories with multimodal learning analytics: A case study on a software engineering course | IEEE Access | IEEE | 20 | Requirements engineering, agile development, multimodal learning analytics, social network analysis |
| 8 | Beagon et al. (2019) | Problem-based learning: student perceptions of its value in developing professional skills for engineering practice | European Journal of Engineering Education | Taylor & Francis | 18 | Engineering practice, professional skills, problem based learning, employability, transition |
| 9 | Ngo & Phan (2019) | Design of an open platform for multi-disciplinary approach in project-based learning of an EPICS class | Electronics | MDPI | 18 | Service learning, robotics, open platform, automated vehicle, EPICS |
| 10 | Mitchell & Rogers (2020) | Staff perceptions of implementing project-based learning in engineering education | European Journal of Engineering Education | Taylor & Francis | 17 | Problem-based learning, faculty developmen |

# Discussion

The systematic searching method adopted in this study identified how professional skills development in engineering education has undergone a modest increase in the level of publication activity over the last 5 years. The subject areas of the publication dataset are predominantly in the following areas: engineering education, students, professional skills, professional aspects, teaching, curricula, surveys, engineers, problem based learning, and education. Bibliometric analysis identified a number of co-occurrence network maps. The co-occurrence map for keywords includes six distinct clusters of keywords and the top ten keywords in terms of occurrences and corresponding total link strength are as follows: engineering education, students, professional skills, professional aspects, teaching, curricula, surveys, problem based learning, engineers, and students. Whereas the co-occurrence map for text is grouped in three distinct clusters that each include a cross-section of 24 terms that are grouped according to co-occurrence, e.g. in one cluster there are the terms: ability, assessment, communication, course, problem, professional skill, student, teaching, team, technology, and time. Finally, the co-occurrence map for author countries is based on 39 countries in 15 clusters, although in many cases the clusters are single countries. The dataset correlates with the descriptive data analysis through USA, China and UK having the highest density of publications in the network map.

In terms of content analysis, a number of publications highlighted that experiential learning is often considered as an optimal mechanism to support professional skills development. The experiential approach, where students ‘learn through doing’, is supported through project-based learning. Indeed, Ngo & Phan (2019) discussed how professional skills are developed through an EPICS (engineering projects in community service) course based on project-based learning (PBL), which had a specific focus on multidisciplinary skills. Whereas Mitchell & Rogers (2020) described how project-based learning differs from more traditional didactic approaches and faculty members need to adopt a more facilitative role. Experiential learning can be linked to the related area of problem-based learning. ElZomor et al. (2018) investigated how problem-based learning is combined with integration of different courses to develop professional skills and confidence in engineering students, including interactional competency skills, confidence in collaboration skills, and confidence in leadership and management skills. In other work, Beagon et al. (2019) identified how a problem-based learning design project supports engineering students to acquire a range of professional skills, such as teamwork, communication skills, understanding of the design process, and self-directed learning abilities.

The mode of delivery of engineering education can impact on the ability to support professional skills development. On this matter, Garduño-Aparicio et al. (2018) identified how practical laboratory exercises (such as those involving robots, embedded systems and mechatronics) enable the development of both technical and professional skills and where the practical sessions can be organized to help students systematically solve real-world problems. Conversely, McFaul & FitzGerald (2020) discussed the use of a virtual reality smartphone app to support the development of presentation skills of undergraduate students, although this form of educational technology was also found to have certain limitations. In other work, Ahmed & Opoku (2022) explored how online teaching of engineering is still dependent on experiential learning so that future graduates are equipped with highly intellectual and professional skills to meet the demands of employers and the industry. Although effectiveness of online delivery is also contingent on certain factors, such as instructors having effective communication skills and teaching style.

In regard to understanding the nature of professional skills in engineering education, researchers have investigated different perspectives. For instance, Sánchez Carracedo et al. (2018) developed a model to integrate professional competences across STEM (science, technology, engineering and mathematics) programs, where the model is based on the use of competency maps and each competency is defined in terms of competency units. Whereas, Jesiek et al. (2018) explored howengineers are often expected to span organizational, cultural, stakeholder, geographic, temporal, and other boundaries; such boundary spanning competencies can be viewed as important professional skills to be developed by engineering students. Finally, Noel et al. (2018) investigated how collaborative writing of user stories is an important professional skill to be developed by students on software engineering courses.

# Implications for Engineering Management Programs

This bibliometric review has derived a set of implications for engineering management (EM) programs:

1. Suitable opportunities for project-based learning should be incorporated in EM programs to allow professionals skills and knowledge to be gained by students. This form of experiential learning could be through a group-based capstone project – thereby enabling teamwork, communication skills, design skills and self-directed learning abilities.
2. The integration of problem-based learning throughout EM programs and courses not only allows theory to be demonstrated but also helps to develop problem-solving skills and the confidence of students as well as interactional competency skills, collaboration and wider engineering management skills.
3. Appropriate digital solutions can be employed to support presentation and communication skills development on EM programs (such as through virtual reality), although caution is needed when designing such approaches. Furthermore, online course delivery enables students on EM programs to be able to engage with digital material in real-time combined with other digital approaches, although caution is needed as online delivery requires a specific approach tailored to this form of teaching when compared to traditional teaching.
4. EM programs can be designed to incorporate different perspectives (such as disciplinary, industrial, organizational, technological, ethical and social) and this holistic viewpoint provides opportunities for students to appreciate the application of EM concepts and knowledge in the professional workplace. It is further recommended that such perspectives are integrated on EM programs from the outset and not simply left for a standalone class at the end of the program.
5. Professional skills and knowledge development on EM programs should allow students to enter the workplace with an array of competences that are relevant to the societal and industrial challenges of today (and the future). This includes an awareness of contemporary issues, such as the challenges of sustainable development and opportunities arising from digital transformation and Industry 4.0 related digital technologies (such as big data analytics, artificial intelligence and augmented reality).
6. The use of competency maps and other pedagogic planning tools are encouraged when new EM programs are designed to ensure an adequate coverage of professional skills and knowledge. Furthermore, benchmarking new EM programs with existing programs can help to identify best practice approaches.

# Conclusions and Future Work

This study has provided the results from a bibliometric review of professional skills development in engineering education, which has enabled a set of implications for engineering management programs to be derived. Engineering managers need to be able to draw on an integrated set of skills and knowledge across the academic discipline of engineering management combined with appropriate professional skills. Traditional teaching methods and examinations can however encounter problems when professional skills are the required learning outcomes. Consequently, experiential learning is advocated, which can be based on project-based or problem-based approaches. Furthermore, there continues to be developments in regard to the classification of professional skills as well as investigation of technology-enabled learning and other digital approaches.

Future research is suggested to develop organizing frameworks to support practitioners designing EM programs with learning outcomes associated with professional skills. Empirical studies are recommended, such as mixed method studies involving qualitative theory development followed by quantitative hypothesis testing through a survey.

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