Using text analytics in benchmarking an engineering management major in a master of engineering course

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Introduction

The modern disciplines of engineering and management are closely linked. The American mechanical engineer Frederick Winslow Taylor (1856-1915) is known as the 'father of scientific management'. Another American mechanical engineer Henry Laurence Gantt (1861-1919) adapted Taylor's work study methods and is known for developing charts that graphed project activity versus elapsed time. The French mining engineer Henri Fayol (1841-1925) divided management into 'planning, organisation, leading, coordinating and controlling', a model still used today. In Australia, as far back as 1968 it was identified that, "In all phases of practice in the profession the technical work is coupled, to a greater or lesser extent, with engineering management." (Lloyd, 1968, p. 43) Later, in 2001 (Samson, 2001) noted that, "shortly after beginning their careers, many professional engineers move from spending the bulk of their time solving technical problems to doing other things...They are managerial activities" (p. xvi). The importance of management in engineering practice, business and education continues to be reported internationally (Lewis & Oppenheim, 2016; Paton & Wagner, 2014; Pons, 2016).

In recent years, in the face of static and then declining domestic enrolments in Australian university engineering education, the sector has continued to grow through a significant increase in international student enrolments. The latest available data (2017) indicate that the annual growth in international student enrolments in coursework master's courses has been two to three times that of any other engineering student group in recent years (Australian Council of Engineering Deans, 2019). Predictably, engineering coursework master's courses have been driving the growth of many Australian engineering academic units. Available data do not clearly indicate into which disciplines engineering coursework master's students are enrolled, however anecdotal evidence indicates that master of engineering management courses and master of engineering courses with an engineering management major sequence are popular, with many Australian engineering academic units offering such courses.

Establishing definitive student enrolment and load data is difficult, as some students may study part-time, and courses offering engineering management as a major sequence may also permit students to effectively complete a second 'major' via selection of elective units. At Deakin University, enrolments into the engineering management major sequence of the Master of Engineering (Professional) course have outnumbered enrolments into other engineering discipline areas in recent years. Based on student enrolments in the compulsory unit sets that define each discipline major sequence, in 2018, approximately half of all enrolments were in the engineering management major sequence. Given the importance of the engineering management major sequence, it was reviewed to ensure its educational and professional value, as well as its market attractiveness, as one element of the university major course review process for the Master of Engineering (Professional) course. To help inform this review, a sector benchmarking research investigation of master's-level coursework engineering management courses in Australia was undertaken.

Course benchmarking based on auditing of the titles and/or syllabus descriptions of units of study (subjects) in course outlines published online is reported in a wide range of discipline areas. Examples include: exercise units in US medical courses (Cardinal, Park, MooSong, & Cardinal, 2015); animal welfare units in US veterinary courses (Shivley, Garry, Kogan, &

Grandin, 2016); unit topics in master of landscape architecture courses in North America (Langley, Corry, & Brown, 2018); sustainability content in Australian management courses (Fisher & Bonn, 2011); topic coverage in introductory accounting units in Australia (Palm & Bisman, 2010); information systems (IS) content in UK IS courses (Stefanidis & Fitzgerald, 2010); and, units in US business analytics courses (Gorman & Klimberg, 2014). Similarly, in STEM disciplines: cyber-security content in UK computer science courses (Ruiz, 2018); entrepreneurship and enterprise education (EEE) units in Irish engineering courses (Gibbons & Bhrádaigh, 2015); and, public transportation content in US civil engineering courses (Oswald Beiler, 2018).

Beyond simple tabulations of results, a range of increasingly sophisticated methods of analysis and visualisation of course benchmarking data is reported in the literature. This includes: pie charts of percentages of topic content (Ruiz, 2018); a ranked histogram of frequency of appearance of knowledge domains or concepts (Langley et al., 2018; Oswald Beiler, 2018); a heat map grid of depth of topic coverage versus university (Gorman & Klimberg, 2014); a word cloud of EEE-related unit titles in engineering courses (Gibbons & Bhrádaigh, 2015); a force-directed network visualising relationships in course enrolment data (Chen & Xue, 2018); and, latent Dirichlet allocation (LDA – a statistical method to optimally allocate words in a body of text to a set of latent/unknown topics that provide a structure to the text) to identify topics in unit syllabi for engineering courses in Japan (Nakamura & Akakura, 2018).

In the research presented here, we firstly identified Australian master's-level engineering management courses, and then identified all units of study in those courses relating to engineering management. Drawing inspiration from the final three literature sources above employing text analytics and data visualisation methods, the titles of all the identified units of study were used as the input to a text analytics analysis and visualisation process. This process was used to identify the relative frequency of, and relationships between, the key engineering management themes present in the unit titles. The output from this process was used to inform the overall review of the engineering management major sequence of the Master of Engineering (Professional) course at Deakin University. We present the details of the method used, a summary of the results, and a discussion of the findings. The text analytics method presented may be a useful tool for others undertaking similar course benchmarking exercises.

Methodology

In the second half of 2018, a survey of the websites of all Australian university engineering academic units was conducted to identify publicly identifiable master of engineering management courses and master of engineering courses with an engineering management major sequence. The structures of these identified courses were examined, and all units of study relating to engineering management were identified. The titles of all the identified units of study were used as the input to a text analytics analysis and visualisation process. The use of publicly available online data is exempt from ethics approval. Text analytics approaches offer a number of methods to analyse and visualise the text data. In the work presented here, we use the text analytics software package KH Coder (Higuchi, 2017) to analyse the content of the unit titles. KH Coder was selected as it is free and provides a range of analysis and visualisation options.

When analysing text, common words and parts of speech, such as 'I', 'a', 'the', etc., add little to the analysis, and their relatively high frequency often masks the words/terms that are actually of significance (Bolden & Moscarola, 2000). KH Coder supports the use of a dictionary of 'stop words', that is, words to be ignored in any analysis of the text. A stop word dictionary was developed based on the example English stop word dictionary supplied with KH Coder, after inspection to remove any words likely to be relevant in the context here, such as 'computer'. In text analytics, it is also important to account for the presence of inflected and/or derived forms of words, for example, a key root word such as 'design' may

also be present in the source text as ‘designing’. KH Coder implements ‘stemming’ to consolidate inflected and derived words into their root form. Here we use stemming via lemmatisation based on English parts of speech (nouns, proper nouns, adjectives, verbs, etc.) (Bolden & Moscarola, 2000). In text analytics, a ‘unit of analysis’ is required, that is, what is the smallest elemental grouping of text upon which the analysis will be based? Here the unit of analysis is the title for each identified engineering management unit of study.

KH Coder supports a range of text data analysis and visualisation methods. In this work we use co-occurrence network (CON) analysis (Palmer & Hall, 2016). Co-occurrence refers to the presence of two (or more) words/terms in the same unit of analysis (Namey, Guest, Thairu, & Johnson, 2007). KH Coder uses the Jaccard distance (Netzer, Feldman, Goldenberg, & Fresko, 2012) as a measure of co-occurrence for term pairs. Based on specifying the minimum frequency of occurrence of a term for inclusion in the CON analysis and visualisation, terms appear as circles/bubbles in a network plot based on the Fruchterman and Reingold (1991) layout algorithm. Frequently co-occurring terms in the visualisation are connected by lines.

Results

In addition to the Deakin University course major sequence, the survey identified 11 master of engineering management courses and master of engineering courses with an engineering management major sequence. Those courses and major sequences contained 194 units of study related to engineering management, and the titles of those units contained more than 700 words which were used as the input for a text analytics analysis. Figure 1 is the CON visualisation of the relationships between the terms in the 194 unit titles produced by the KH Coder analysis. Figure 1 includes a scale to indicate the frequency of occurrence of each term visualised. Solid network links connecting terms represent stronger relationships; dashed network links represent weaker relationships. Indicative term ‘communities’ (clusters) based on the strength of connection between terms are indicated by colour.

Discussion

There are some limitations to the research presented here. While the course review exercise had a forward-looking intent, the survey of university websites captured a snapshot of current data at a single point in time. The survey was based on unit titles only, and the actual content of the units may have been broader, addressing themes not represented in the titles. The data set of unit titles was relatively small, although the CON analysis method employed here should still produce useful results. The CON analysis method is algorithmic, and applies quantitative methods to data that are essentially qualitative, so the results require interpretation. For example, as noted above, the indications of term communities in the CON visualisation are indicative only. With these limitations in mind, we can consider the results in more detail.

Predictably, Figure 1 shows that the terms ‘engineering’ and ‘management’ both had a relatively high frequency of occurrence in unit names, and often appeared together. Other terms appearing in the same blue network community referred to the topic areas ‘project management’, ‘industry project’ and ‘research methods’. We conclude that this community captured core structural features commonly present in many master of engineering management courses and major sequences. Aside from the blue community, the CON analysis process highlighted four principal term communities, coloured purple, yellow, green and red in Figure 1. There was also one other minor term community coloured orange that appeared to be a subsidiary of the red community.

The purple community includes terms and term groups such as ‘leadership’, ‘performance’, ‘entrepreneurship’, ‘innovation’, ‘business’, ‘system design’, ‘system analysis’ and ‘strategy’. This community can be summarised as engineering strategic management. The yellow

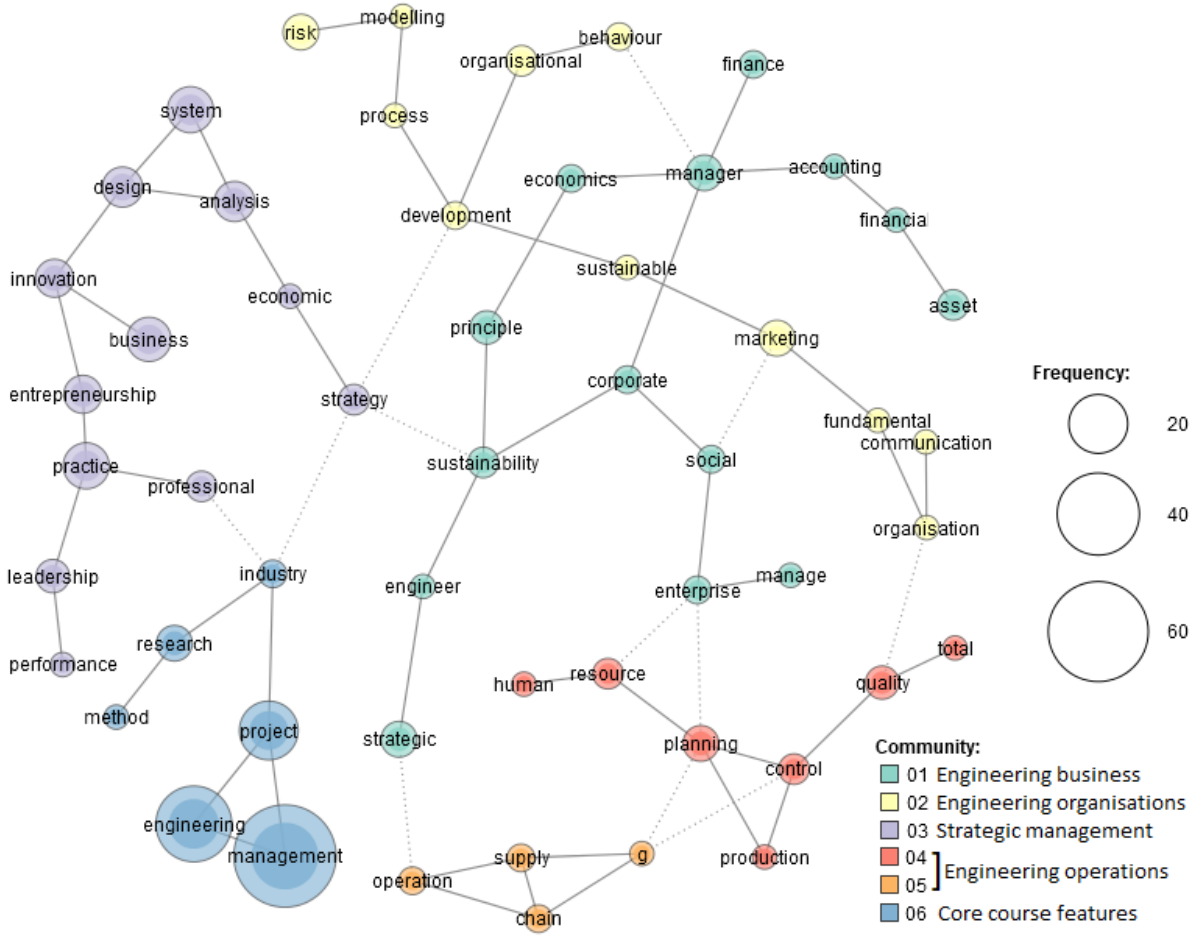

Figure 1: Co-occurrence network of text terms in unit titles in Australian master of engineering management courses

community includes terms and term groups such as ‘organisation’, ‘organisational behaviour’, ‘organisational development’, ‘communication’, ‘marketing’, ‘process modelling’ and ‘risk’. This community can be summarised as engineering organisations. The green community includes terms and term groups such as ‘financial’/’finance’, ‘accounting’, ‘economics’, ‘sustainability principle’ and ‘corporate social’. This community can be summarised as engineering business. The red community, and the smaller related orange community, include terms and term groups such as ‘quality control’, ‘total quality’, ‘human resource’, ‘production planning’, ‘production control’, ‘operation’ and ‘supply chain’. This community can be summarised as engineering operations.

Discipline majors in the Master of Engineering (Professional) course at Deakin University consist of a four-unit sequence. While the natural appearance of four principal term clusters in the CON was certainly suggestive, the purpose of the CON visualisation was not to literally be the template for a new structure for the engineering management major sequence. Rather, the research findings were one input into the review of the engineering management major sequence. The principal reference point for the review was the list of intended learning outcomes for the engineering management major sequence that describe what graduates should be able to do on the completion of their studies. These were established as:

- Propose business performance improvements by mapping the environment of an engineering business and performing situational analysis of engineering activities;
- Conceptualise, strategize, and execute engineering projects, processes and systems for solving real-world problems;
- Provide directions for integrating information and technological advancements for adaptation through research and development, continuing professional development and performance planning and review activities; and

- Contribute to the management of engineering activities within an engineering business in an effective manner.

Through a process of elaboration and refinement, these learning outcomes were expanded into four unit syllabi, teaching schedules and accompanying assessment plans, with the following provisional titles:

- Engineering Process and Operations Management;
- Managing Engineering Projects;
- Engineering Organisations; and
- Strategic Management in Engineering.

The proposed new four-unit engineering management major sequence will now be submitted for institutional approval and a timetable for implementation developed.

The history of management studies in Australian undergraduate engineering courses is well documented (Palmer, 2000, 2006; Young, 1991). The 1988 Williams review of engineering education (Williams, 1988) found that employers judged graduates' technical skills as satisfactory, but their management skills as unsatisfactory. Additionally, Williams conducted a national survey of students and graduates that found management skills had the largest discrepancy in rating between "what should have been covered" and "what has been covered". Lloyd (1994) describes the development by the Institution of Engineers, Australia (IEAust, now Engineers Australia) of a policy (Institution of Engineers Australia, 1991) requiring that approximately ten per cent of the content of undergraduate engineering courses be 'management studies'. The policy included a suggested model study structure as presented in Figure 2, and a brief syllabus for each topic identified.

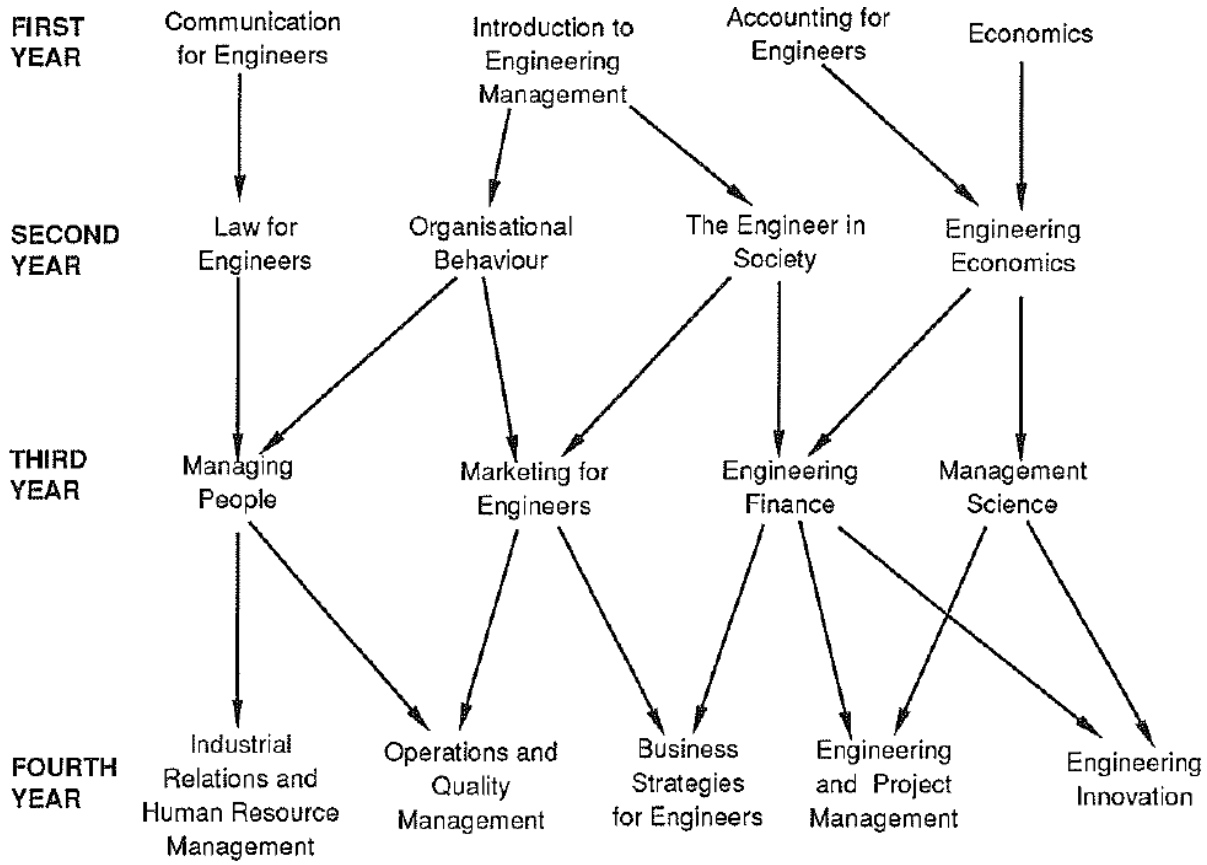

Figure 2: IEAust model study structure for management studies in engineering undergraduate courses (labelled Exhibit 4 in Institution of Engineers Australia (1991) – reproduced with permission)

Following the 1996 Johnson review of engineering education (Johnson, 1996), the management studies policy was allowed to lapse and was removed. Interestingly, the model structure from 1991 in Figure 2 was presented in the form of a network of topic areas, similar to the resultant analysis visualisation presented in Figure 1, although Figure 2 is a directed network proposing prerequisite links, rather than just associations, between the topic areas. Many of the topic areas presented in Figure 2 are effectively identical to those identified in Figure 1. Topic areas present in the 1991 model that did not appear in the CON visualisation include law and industrial relations – two areas that remain very relevant for engineering graduates in practice today (Hayes, Maslen, Scott-Young, & Wong, 2018; Pons, 2016; Stanford, 2017; Todd, Ellem, Goods, Rainnie, & Smith, 2017). As noted above, it is possible that law and industrial relations, and potentially other topics, are indeed covered in the contemporary engineering management units identified in this research, but that they do not occur, or occur with sufficient frequency, in the unit titles to appear in the resultant CON visualisation. Additionally, the context for Figure 1 (master's courses) is different to that of Figure 2 (undergraduate courses). The principal purpose of noting the 1991 IEAust model study structure here is to highlight that, although the current terminology may have changed to refer to 'professional practice', management studies for engineering students have an enduring relevance, and that a range of topics remain important.

Conclusion

A new four-unit engineering management major sequence was proposed for the Master of Engineering (Professional) course at Deakin University. The rationale for, and details of, the proposed new major sequence were presented, including the details of a text analytics benchmarking process undertaken to map the content of unit titles found nationally in master of engineering management courses. The proposed new four-unit engineering management major sequence has many elements in common with the model structure for management studies in undergraduate engineering courses that formed part of the Australian engineering course accreditation requirements in the 1990s, and points to the enduring relevance and popularity of management education for engineering students of all levels. The research presented here focussed on master of engineering courses and major sequences specifically with the appellation 'engineering management'. However, it is noted that there are also related master's-level courses with titles such as 'engineering project management', and that the total number of all master's-level 'engineering management' courses appears to have increased since this research in 2018 (Australian Council of Engineering Deans, 2019). The text analytics method presented may be a useful tool for others undertaking similar course benchmarking exercises.

Reviewing the engineering management major sequence naturally leads to a re-examination of the intended aims of that major and, in fact, the entire master of engineering course. What do we want graduates of the course to be able to do? Where do we intend that they will work? What are the knowledge, skills, attitudes and other characteristics that they will need to lead a successful career? Based on consultations with stakeholders, and the likely career trajectories of professional engineers, historical reviews of undergraduate engineering education in Australia have identified the importance of engineering management studies for all engineering students. Another option for the present would be to consider making the engineering management unit sequence part of the core stream of units for all discipline majors in the Master of Engineering (Professional) course at Deakin University. This would be a more significant undertaking than just revising the engineering management major sequence, and in effect would make the existing engineering management major sequence as a separate offering obsolete. Given the apparent market demand for master of engineering studies with the distinct title 'engineering management' that is currently observed, such a change would be bold, and would certainly require a significant marketing effort to inform potential students, recruiting agents and other stakeholders of the change.

References

Australian Council of Engineering Deans. (2019). *Australian Engineering Education - Student, Graduate and Staff Data and Trends - March 2019*. Carindale, Queensland: ACED Inc.

Bolden, R., & Moscarola, J. (2000). Bridging the quantitative-qualitative divide: the lexical approach to textual data analysis. *Social Science Computer Review, 18*(4), 450-460. doi:10.1177/089443930001800408

Cardinal, B. J., Park, E. A., MooSong, K., & Cardinal, M. K. (2015). If Exercise is Medicine, Where is Exercise in Medicine? Review of U.S. Medical Education Curricula for Physical Activity-Related Content. *Journal of Physical Activity & Health, 12*(9), 1336-1343.

Chen, X., & Xue, C. (2018). Network Visual Exploration for the Cooperation Map of Courses in Different Major Curricula. *Educational Sciences: Theory & Practice (Kuram ve Uygulamada Egitim Bilimleri), 18*(6), 2874-2884.

Fisher, J., & Bonn, I. (2011). Business sustainability and undergraduate management education: an Australian study. *Higher Education, 62*(5), 563-571. doi:10.1007/s10734-010-9405-8

Fruchterman, T. M. J., & Reingold, E. M. (1991). Graph drawing by force-directed placement. *Software: Practice and Experience, 21*(11), 1129-1164. doi:10.1002/spe.4380211102

Gibbons, C., & Bhrádaigh, E. N. (2015, 13-15 July). *A review of the current level of Entrepreneurship and Enterprise Education in Irish Engineering schools.* Paper presented at the Research in Engineering Education Symposium, Dublin.

Gorman, M. F., & Klimberg, R. K. (2014). Benchmarking Academic Programs in Business Analytics. *INFORMS Journal on Applied Analytics, 44*(3), 329-341. doi:10.1287/inte.2014.0739

Hayes, J., Maslen, S., Scott-Young, C., & Wong, J. (2018). The rise of defensive engineering: how personal liability considerations impact decision-making. *Journal of Risk Research, 21*(9), 1131-1145. doi:10.1080/13669877.2017.1391319

Higuchi, K. (2017). KH Coder (Version 3.Alpha.09b). Japan: Koichi Higuchi. Retrieved from http://khc.sourceforge.net/en/

Institution of Engineers Australia. (1991). *Policy on Management Studies in Professional Engineering Undergraduate Courses*. Canberra: Institution of Engineers, Australia.

Johnson, P. (1996). *Changing the Culture: Engineering Education into the Future*. Canberra: The Institution of Engineers, Australia.

Langley, W. N., Corry, R. C., & Brown, R. D. (2018). Core Knowledge Domains of Landscape Architecture. *Landscape Journal, 37*(1), 9-21. doi:10.3368/lj.37.1.9

Lewis, T., & Oppenheim, T. (2016). Integrating a Business Minor with an Engineering Course of Study. *Journal of Management & Engineering Integration, 9*(2), 100-109.

Lloyd, B. E. (1968). *The Education of Professional Engineers in Australia*. Melbourne: The Association of Professional Engineers, Australia.

Lloyd, B. E. (1994). *The New Institution 1989-1994 - Positioning the Institution of Engineers, Australia for the New Millennium*. Canberra: Institution of Engineers, Australia.

Nakamura, S., & Akakura, T. (2018, 4-7 Dec. 2018). *Topic Analysis of Syllabus for Faculty of Engineering in the Japanese National University.* Paper presented at the 2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE).

Namey, E., Guest, G., Thairu, L., & Johnson, L. (2007). Data reduction techniques for large qualitative data sets. In G. Guest & K. M. MacQueen (Eds.), *Handbook for team-based qualitative research* (pp. 137-162). Plymouth, UK: Altamira Press.

Netzer, O., Feldman, R., Goldenberg, J., & Fresko, M. (2012). Mine your own business: market-structure surveillance through text mining. *Marketing Science, 31*(3), 521-543. doi:10.1287/mksc.1120.0713

Oswald Beiler, M. R. (2018). Public Transportation Education: Inventory and Recommendations on Curricula. *Journal of Professional Issues in Engineering Education and Practice, 144*(3), 05018005. doi:10.1061/(ASCE)EI.1943-5541.0000369

Palm, C., & Bisman, J. (2010). Benchmarking Introductory Accounting Curricula: Experience from Australia. *Accounting Education, 19*(1-2), 179-201. doi:10.1080/09639280903254959

Palmer, S. (2000). Management Education in Australian Engineering Undergraduate Courses. *Engineering Management Journal, 12*(3), 3-9.

Palmer, S. (2006, 10-13 December). *The rise and fall of management: undergraduate engineering management education in Australia.* Paper presented at the 17th Annual Conference of the Australasian Association for Engineering Education, Auckland.

Palmer, S., & Hall, W. (2016, 6-8 July). *A text analytics evaluation of a first-year engineering project-based unit.* Paper presented at the 8th International Symposium on Project Approaches in Engineering Education, Guimarães.

Paton, R. A., & Wagner, R. (2014). Management Education makes a Difference: Enhancing German Engineering Performance. *Long Range Planning, 47*(5), 277-298. doi:10.1016/j.lrp.2012.06.002

Pons, D. (2016). Relative importance of professional practice and engineering management competencies. *European Journal of Engineering Education, 41*(5), 530-547. doi:10.1080/03043797.2015.1095164

Ruiz, R. (2018, 16-18 January). *A Study of the UK Undergraduate Computer Science Curriculum: A Vision of Cybersecurity.* Paper presented at the 12th International Conference on Global Security, Safety & Sustainability, London.

Samson, D. (2001). *Management for Engineers* (3rd ed.). Frenchs Forest, New South Wales: Pearson Education Australia.

Shivley, C. B., Garry, F. B., Kogan, L. R., & Grandin, T. (2016). Survey of animal welfare, animal behavior, and animal ethics courses in the curricula of AVMA Council on Education-accredited veterinary colleges and schools. *Journal of the American Veterinary Medical Association, 248*(10), 1165-1170. doi:10.2460/javma.248.10.1165

Stanford, J. (2017). Automotive surrender: The demise of industrial policy in the Australian vehicle industry. *The Economic and Labour Relations Review, 28*(2), 197-217. doi:10.1177/1035304617709659

Stefanidis, A., & Fitzgerald, G. (2010). Information Systems Curricula in the UK: A Survey of Undergraduate Courses (research-in-progress). *Innovation in Teaching and Learning in Information and Computer Sciences, 9*(1), 87-99. doi:10.11120/ital.2010.09010087

Todd, P., Ellem, B., Goods, C., Rainnie, A., & Smith, L. (2017). Labour in global production networks: Workers and unions in mining engineering work. *Economic and Industrial Democracy, 2017*(January), 1-23. doi:10.1177/0143831x16684964

Williams, B. (1988). *Review of the Discipline of Engineering*. Canberra: Commonwealth Tertiary Education Service.

Young, E. J. (1991). The Australian Thrust in Management Education in Engineering Undergraduate Courses. *Engineering Management Journal, 3*(3), 3-7.

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