Citation network analysis of documents on engineering and technology education

Kristijan Breznik†‡ & Vesna Skrbinjek†

International School for Social and Business Studies, Celje, Slovenia†
College of Industrial Engineering, Celje, Slovenia‡

ABSTRACT: Over the last decade, there has been significant increase of interest in the subject area of engineering and technology education. It has been documented by an increasing number of authors and articles, and in journals dealing with this interesting and important topic. In the article, all documents that can be obtained from the Web of Science and are related to the topic were analysed, providing a list of the most important documents with authors in the field, and the journals that serve as promoters and disseminators of scientific knowledge. The authors and documents have been analysed using traditional statistical methods. In addition, journals have been classified according to their importance in terms of the number of articles published and their visibility. Using advanced statistical techniques, a network of citations among documents has been produced, introducing the field of scientometrics. Actors in the network are authors of documents from the area of engineering and technology education, and citations among them explain relationships in the network. This article provides insight into the developments of the field since its creation until today. It can also be seen as a comprehensive review of the field and as important material for both beginners in this field, as well as for already established scholars.

Keywords: Engineering education, technology education, network analysis, meta-analysis, scientometrics

INTRODUCTION

The digital transformation of the economy and society has increased the rate at which engineering science occurs and is being published. At the same time, it can be observed that the nature of research has become more interdisciplinary and multidisciplinary evolving new scientific fields at an increasing pace. The New Skills Agenda for Europe recognises the challenges of technology and globalisation in higher education, and highlights to encourage multidisciplinarity in all fields [1].

The overwhelming volume of information enabled by free access Internet sources lacks transparency and provides an endless overview on research often with no information on relevance and scientific impact of a particular subject field. Therefore, methodologies to gather and present relevant research works are needed to equip scholars with up-to-date knowledge and to help them use this knowledge.

Engineering education has gained considerable attention in the last decade, which can be observed with a notable scale-up of departments and degree programmes, high-profile publication outlets, research agendas and meetings [2].

According to Borrego and Bernhard establishment of engineering education research conferences, interest groups within engineering education societies, PhD programmes, departments and centres at universities provided support for international dissemination [3]. Evidence on international and interdisciplinary orientation of engineering education is being provided through research documents, which are being published in a broad range of archival journals, conference proceedings and reports [3]. In the same way, technology education has gained popularity in parallel with increasing research interest in STEM, information technologies, sustainability issues and mobile learning grew.

Previously, other authors have provided insights into the field of engineering education, e.g. Wakant, Williams, Neto, Borrego, Jesieg among others. Research on how engineering education evolved can be found in Wakant [4][5], Borrego [6], Borego et al [7][8], Jesiek et al [2] and Malmi et al [9]. Borrego provided a study on publication patterns of engineering education coalitions which served as a case study of the recent history of engineering education [6].

Jesieg et al contribution was to clarify the gabs in contextualisation and terminology of engineering education research [2]. Borrego and Bernhard provided a review of journals focusing on engineering education research [3]. Borrego et al

also dealt with methodology approaches in engineering education research and suggested a systematic review approach in contrast to narrative reviews, which are the most often used [7]. The most recent review of engineering education publications was done by Malmi et al who focused on exploring how papers link to theoretical work and how research processes have been designed and reported [9].

Likewise, a review of technology education research was made by Williams [10][11]. In his first publication, Williams provided evidence of the most frequent topics of technology education research in journals and conference publications from 2006 to 2010 [10] and in his second publication, he covered the period from 2011 to 2013 [11]. He also provided some thoughts on developments and trends in technology education research. Zuga, on the other hand, reviewed dissertations and other research literature published between 1987 and 1993 focusing on K-12 and teacher education in technology education [12].

In recent years, systematic content analysis and citation analysis have become the major methods of research review studies [13]. Using citation analysis as a method to provide information on the most cited engineering and technology education publications, Wakant first reviewed articles published in the Journal of Engineering Education (JEE) and later extended his research applying citation analysis of JEE and the European Journal of Engineering Education (EJEE) [14][15], Williams et al provided an update with the same method on two conferences and both journals [16].

A three-stage content analysis, which included journal sampling, journal examination and journal identification was done by Chou and Chen to identify the worldwide engineering education journals [17]. In addition, other sub-fields of engineering education were analysed; for example, an analysis of the most cited articles in software engineering journals was done by Wohlin [18], and Gantar et al [19]. Tang and Tsai used document co-citation analysis, social network analysis and exploratory factor analysis to identify research on educational technology in science education [20].

The research described here focuses on providing a clearer overview of publications in the engineering education and technology education fields with the aim of strengthening both disciplines. The authors of this article provide information on how both disciplines evolved in recent years by demonstrating the frequency of occurrence of the most cited publications, authors and journals in the Web of Science database.

The intention was to understand the field of engineering and technology education better, and to identify the most visible publications and relevant authors. Similar to the approach taken by Tang and Tsai [20], a visual demonstration of citations by applying a network analysis technique has been provided.

RESEARCH METHODOLOGY

The research process was implemented in three stages. First, all available information on all documents on topics *engineering education* and *technology education* were extracted from the Web of Science (WoS) database. This involved downloading information on 9,718 documents, until the end date of April 2017. The dataset included the title and type of a document; authors; journal (or proceedings or book); and references, etc. Second, a descriptive analysis of the dataset obtained was conducted. It can be classified as meta-analysis of the documents. Third, a network of citations between documents was designed. Actors in the network are documents from the field of engineering and technology education. Citations among them explain the relationships in the network. The resulting network of documents and their citations defines a directed and unweighted large network. The direction of each link in the network was determined by a citation from a document, which cites the document that has just been cited. Similarly, a weight of each link represents the number of citations between documents (in the directed kind of sense). A citation network is, by definition, also an acyclic type of network. This property has been used in further analysis. For the analysis of networks, the Pajek program was used [21].

RESULTS

Meta-analysis

Documents on the topics *engineering education* and *technology education* from the WoS can be classified according to several criteria. Regarding the publication type (PT), there were 427 books, 6,298 journals and 2,993 series. Documents can be classified as articles (4,132), proceedings papers (4,078) and others (1,508), which include editorial material, letters, reviews, meeting abstracts, etc. The number of documents by year is presented in Figure 1. Since the year 2017 was not represented in full, it was omitted from Figure 1.

First document on the topic was published in 1901. Afterwards there was slow, but steady growth of documents on the analysed topic until the year 2000 in which 114 documents were recorded. Then, the growth of documents began to flourish and in less than 10 years (2009) it doubled to 236. From 2013, the number of documents exceeded 300 and finally in 2016 there were 451 documents altogether. Eighty per cent of all documents are articles. The authors also found that from 2011, a significant increase of proceedings papers emerged (more than 600 per year), which has distorted the data. Therefore, these proceedings papers were eliminated from the analysis.

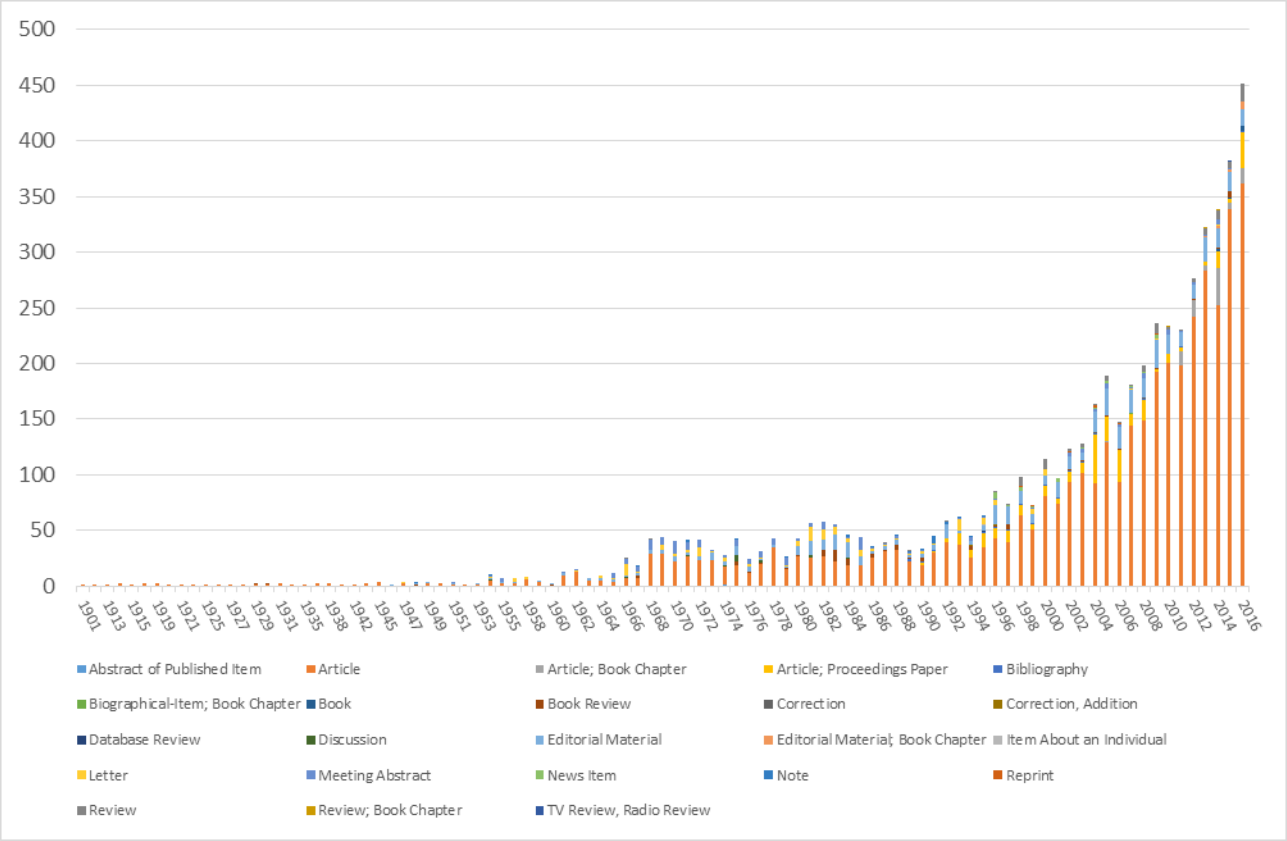

Figure 1: Published documents by year and document type.

Scientific journals are the most important channel for the dissemination of scientific knowledge. Among the important information about a journal is the number of citations that the document receives. In Table 1, the ten journals with the most documents published on the observed topic are presented. In addition, information about journal quality (its impact factor) with the total number of citations of documents published on the topic, has been presented.

Table 1: Published documents by journals with additional information.

Journal name	Journal abbreviation	IF	ND	NC
International journal of engineering education	IJEE	0.559	801	3,014
IEEE transactions on education	ToE	1.33	374	2,515
Journal of professional issues in engineering education and practice	JPIEEP	0.538	227	1,020
International journal of technology and design education	IJTDE	0.355	196	1,096
Journal of engineering education	JEE	1.739	186	4,463
Engineering education	EE	*	178	1,354
Computer applications in engineering education	CAEE	0.935	173	946
International journal of electrical engineering education	IJEEE	0.302	120	204
IEEE transactions on power systems	ToPS	3.342	86	1,446
IEEE antennas and propagation magazine	APM	0.896	78	393

Legend: IF - impact factor in 2015; ND - number of documents on a topic; NC - number of citations on the topic; * - not existing any more.

Besides being published in an important journal, citation statistics also constitute an important part of a document's visibility. In Table 2 the ten documents with the highest number of citations received in WoS until April 2017 have been presented.

Table 2: Published documents by journals with additional information.

First author	Title	Journal abbreviation	YP	NC	DT
Felder, R.M.	Learning and teaching styles in engineering-education	EE	1988	1,231	Article
Zimmerman, R.D.	MATPOWER: steady-state operations, planning, and analysis tools for power systems research and education	ToPS	2011	928	Article
Dym, C.L.	Engineering design thinking, teaching, and learning	JEE	2005	557	Review
Flourentzou, N.	VSC-based HVDC power transmission systems: an overview	ToPE	2009	492	Review

Felder, R.M.	Understanding student differences	JEE	2005	333	Review
Feisel, L.D.	The role of the laboratory in undergraduate engineering education	JEE	2005	304	Article
Hazelrigg, G.A.	A framework for decision-based engineering design	JMD	1998	232	Article
Ma, J.	Hands-on, simulated, and remote laboratories: a comparative literature review	CSUR	2006	178	Review
Galor, O.	Ability-biased technological transition, wage inequality, and economic growth	QJE	2000	176	Article
Harward, V.J.	The iLab shared architecture a web services infrastructure to build communities of Internet accessible laboratories	Proceedings of the IEEE	2008	149	Article

Legend: YP - year published; NC - number of citations on the topic; DT - document type

Network analysis

The network among documents with a relationship defined as a citation from the document that cited the citing document contains 10,345 nodes representing documents and 19,232 directed links among them. It can be classified as a sparse network, its density is 0.00018, i.e. 0.18 per mille of all possible directed lines are realised. Average degree per node is 3.72. Since the network of citations is acyclic, first nodes (sources) and last nodes (sinks) can be identified.

In the network, there are 7,721 sources and 5,641 sinks. The maximum input degree is 168 (the highest number of citations received - Kolb's document on learning styles from 1984) and the maximum output degree is 72 (the highest number of citations given - Froyd's et al document on five major shifts in 100 years of engineering from 2012). The network consists of 4,497 weak components. The largest weak component consists of 5,692 nodes (over 55% of all nodes in the entire network), and other components are significantly smaller. The network with components of size and at least two nodes is displayed in Figure 2. The prevalence of the largest component can be clearly observed. Small components are composites of one article and its citations.

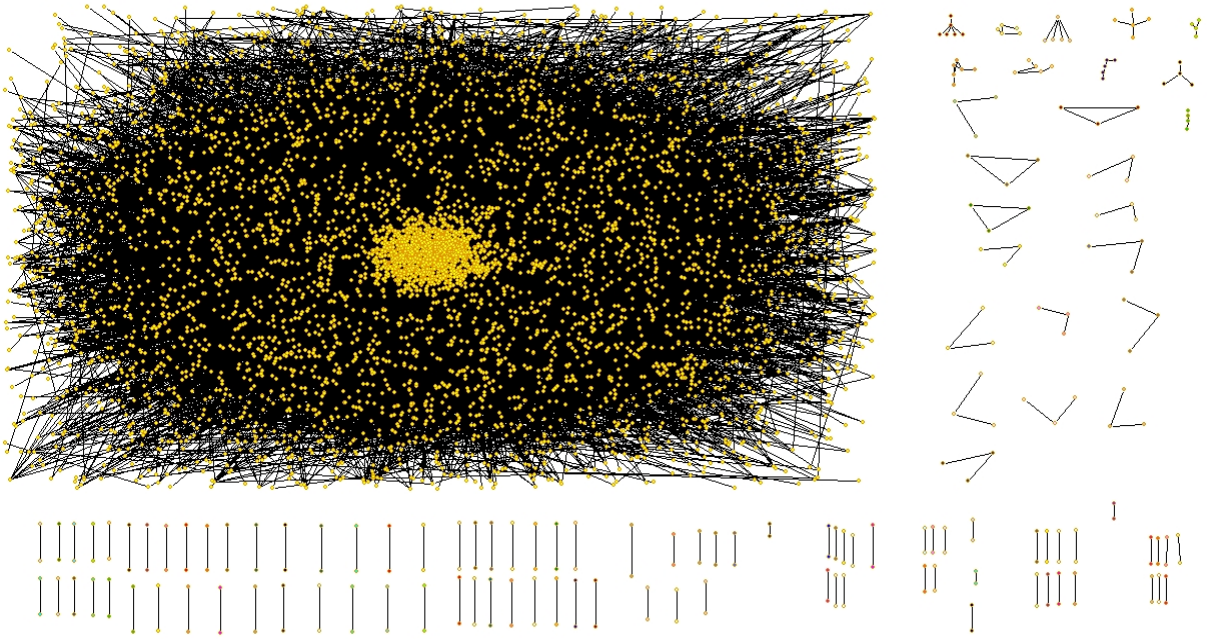

Figure 2: Citation network without singletons.

Main path analysis is one the most often used methods in citation network analysis [22]. The main path consists of the arcs with the highest weights and in this case, the most important documents on the topic of engineering and technology education. For calculating the weights on arcs, SPC (search path method) [22] was used. The main path is displayed in Figure 3.

DISCUSSION AND CONCLUSION

Engineering and technology education has the *ability to do cutting edge research* [23] and this ability can be used to foster its development. With the citation analysis, more insight on the most cited documents and authors in the aim to benefit engineering and technology education can be provided. From this meta-analysis, IJEE has by far the most documents published on the observed topic, but the most cited journal was JEE. The article receiving the highest number of citations was one by Felder, R.M. (1988) with the title: *Learning and teaching styles in engineering education* published in EE. Felder, Dym and Feisel provided the most cited articles published in JEE.

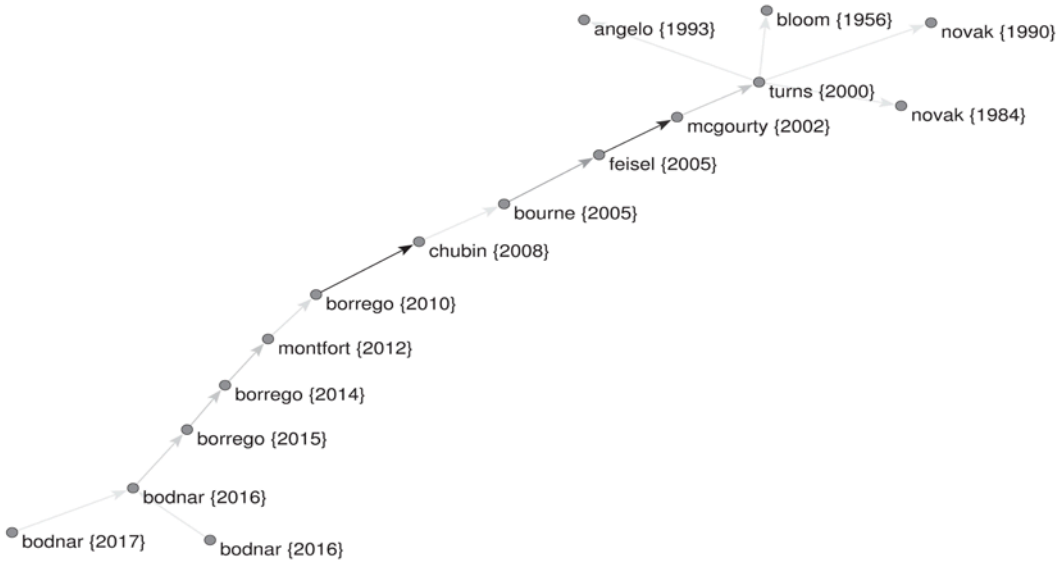

Figure 3: Documents on main path weighted by SPC (search path count).

Main path technique is …*capable of tracing the most significant paths in a citation network and is commonly used to trace the development trajectory of a research field* [24]. Relevant documents and/or journals are the ones with the highest number of citations. With main path analysis, it can be shown, which documents received the most citations and the documents that they cited. In the research here, the main path of citations for engineering and technology education integrated with the work of Turns (2000) in one branch and moves on to Bodnar (2016) where it, then, branches out.

The presented chronological evidence demonstrates that engineering and technology education gained considerable importance only in the last decade. In the main path, Feisel (2005) for whom the authors found in Table 2 can be observed as being the fifth most cited author on the observed topic. Borrego's most cited documents were published in JEE three times, and Bodnar's documents were published in JEE, IJEE and IEEE Transactions on Professional Communication. It was also the case that engineering education documents prevail over technology education documents.

Results obtained are important for many reasons. This article provides insight into the developments of the field since its creation until today. All of what is important in scientific terms in the subject area, the authors and their articles with citations among them in the most important journals, was gathered. It can also be seen as a comprehensive review of the field and as an important material for both, beginners in this field, as well as for already established scholars.

LIMITATION

The authors only analysed publications of journals from the WoS database, therefore, journals included in the Scopus database, such as the Global Journal of Engineering Education, were not included in the analysis. In the future, the research could be extended to include other relevant databases.

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BIOGRAPHIES

Kristijan Breznik works as an Assistant Professor at the International School for Social and Business Studies and at the College of Industrial Engineering in Celje, Slovenia. He obtained his PhD in statistics, in the field of social network analysis, and a Master of Science degree in mathematics, in the field of number theory, both at the University of Ljubljana, Slovenia. His main research interests, besides social network analysis, are data analysis, graph theory, database development, entrepreneurial networks and sports statistics. He is currently the Editor-in-Chief of the International Journal of Management, Knowledge and Learning. He is a member of the Editorial Boards of several prominent journals including the International Journal of Innovation and Learning, the International Journal of Management and Enterprise Development, the International Journal of Management in Education, World Transactions on Engineering and Technology Education, and the International Journal of Value Chain Management. He has authored scientific papers in many international journals, and various conference proceedings and technical papers.

Vesna Skrbinjek works as an assistant at the International School for Social and Business Studies in Celje, Slovenia. She obtained a university degree (in mathematics and geography) at the University of Maribor in 2007, and in early 2015, a PhD at SASS Nova Gorica in the field of higher education funding. She was a young researcher at the International School for Social and Business Studies in Celje. Her main research area is interdisciplinary, with emphasis on the study of higher education, higher education management, funding and quality. She is an editorial assistant for the International Journal of Management and Education (IJMIE) (Inderscience Publishers), which is indexed in international bibliographic databases, including Scopus and ERA.