Engineering Education (Research) in Higher Education Institutions

Rui M. Lima[1], Erik de Graaff[2], Diana Mesquita[3], André Luiz Aquere[4]

[1] Department of Production and Systems, School of Engineering, University of Minho, Guimarães, Portugal
[2] Aalborg University, Aalborg, Denmark
[3] Institute of Education, University of Minho, Guimarães, Portugal
[4] Department of Civil and Environmental Engineering, Faculty of Technology, University of Brasília, Brasília, Brazil

Email: rml@dps.uminho.pt, degraaff@plan.aau.dk, diana@dps.uminho.pt, andre@unb.br

Abstract

The past decades the interest in Engineering Education (EE) and Engineering Education Research (EER) has been increasing all around the world. Nevertheless, educators and researchers in engineering schools that dedicate their time to this field of applied research often find themselves in a reverse flow with the most accepted and traditional career paths. Considering that engineering educators are practitioners of EE and sometimes also researchers in EER subfields, this discussion paper aims to take a snapshot of the state of the art with respect to EE and EER in higher education and the role of higher education institutions (HEI). The approach chosen was to make an exploratory study based on document research, using three main sources: Elsevier Scopus indexing service, Times Higher education university rankings and universities' web sites. Considering the Scopus database, the time threshold was defined as 1970 to the present. Using the search-term "engineering education" it was possible to identify 60250 conference documents and 18610 journal documents. Moreover, it could be established that seven from the top 25 institutions with a higher number of journal publications were also among the top 25 HEI of the Times ranking. Additionally, in all Times Top 25 HEI some kind of organization unit dedicated to staff development could be identified, most of these with some specific organizational initiatives related to EE. Based on this exploratory study the authors conclude that EE and EER mutually benefit from each other and that the combination apparently poses no stumbling blocks to the most recognized research institutions in the world. Finally, the authors argue that this field of applied research potentially has a high impact in the advancement of engineering education.

Keywords: Engineering Education; Engineering Education Research; Active Learning; Project-Based Learning.

1 Introduction

Engineering Education (EE) is gaining an incremental interest in the last years all over the world (Besterfield-Sacre, Cox, Borrego, Beddoes, & Zhu, 2014; Borrego & Bernhard, 2011). This interest is based on the need to improve the education of engineers that should be able to solve complex problems and deal with the engineering challenges (NAE, 2008; UNESCO, 2010). The interest in improving the training of engineers create the need to change engineer education. Changing engineer schools can be based on the five pillars presented by Goldberg and Somerville (2014): joy, trust, courage, openness, collaboration. New approaches should bring joy to students and teachers, and trust is the main ingredient for enjoying teaching and learning, and also for creating an atmosphere of empathy and openness that is necessary for collaboration. In order to create innovative approaches, the stakeholders need a trusting environment. Finally, only courage allows dealing with the natural insecurity that will always accompany a changing environment.

The improvement of a sub-area of knowledge is related to the quality of research developed in this domain. Regarding Engineering Education Research (EER), Borrego & Bernhard (2011) argue that this has now been established as a field of inquiry. Although EER methods and processes can be seen as different from research in engineering (Borrego, 2007), it is strongly linked to the engineering field itself (Bernhard, 2015) and to the improvement of education of engineers. In this line of thought, the National Science Foundation of the USA has a division focused on Engineering Education Centres, investing in the "creation of 21st century engineers and the discovery of new technologies through transformational centre-based research, research in education and inclusion, and research opportunities for students and teachers" (NSF, 2017). This global movement still has opposition in many engineering schools. The statements of the managers and teachers of these institutions are usually aligned with the perceived need to improve engineering education. Nevertheless, there is different perspective about what this means and it could be said that most, or at least a large percentage, of engineering teachers do not recognise the real importance of this field and of the emerging research in this field.

The importance of the results of innovation in engineering education (or in education, higher education, science education or technology education) have been underlined by numerous works: Active Learning (Bonwell & Eison, 1991; Christie & de Graaff, 2017; Freeman et al., 2014; Prince, 2004); Problem and Project-Based Learning (PBL) (Aquere, Mesquita, Lima, Monteiro, & Zindel, 2012; Graaff & Kolmos, 2003; Lima, Dinis-Carvalho, Sousa, Arezes, & Mesquita, 2017; Reis, Barbalho, & Zanette, 2017). Still there is a need to understand to what extent recognised higher education institutions (HEI) are contributing to the field of engineering education research (EER) and to practice improvement in engineering education (EE). This discussion paper aims to take a snapshot of the present state of EE and EER and the role of higher education institutions (HEI). The approach chosen to make this exploratory study, was based on documental research, using three main sources, Elsevier Scopus indexing service, Times Higher education university rankings and universities' web sites.

2 Methodology

Considering the objective defined for this work, and the lack of similar studies an exploratory approach was chosen. Exploratory research approach aims to give first inputs for analysis of fields under research, which allows to create conditions for future in depth studies. In this exploratory study, the approaches selected for data collection were higher education institutions (HEI) sites and articles published in journals indexed in Scopus.

For the bibliometric analysis we used the Scopus database and for the analysis of HEI we used the Times Higher Education ranking for selection of HEI and the web sites for analysis of specific data. The research data collection and analysis were based on the following steps executed at 2017/07/28:

1. Search the database with the following term (using the double quotes): "Engineering education"
2. Analyse the results considering source types, affiliation, authors and countries.
3. Select journals as data source of documents.
4. Select documents after and including 1970.
5. Identify the top 25 bibliometric HEI in this list.
6. Select the top 25 ranking HEI of the Times ranking
7. Search web sites of this Top 25 ranking HEI for centres of Engineering Education or staff development.
8. Cross relate top bibliometric 25 with top 25 ranking HEIs.

The search results showed 18996 documents since 1877, being 386 prior to 1970. Thus, this paper uses the bibliometric data from 18610 documents. Table 6 presents a summary of the documents published since 1970 related to engineering education.

Table 6: Scopus indexed documents published since 1970 – search results of the term "engineering education"

Source type	Numbers
Conference Proceedings	60250
Journals	18610
Book Series	3470
Trade Publications	1648
Books	416
Reports	150
Total	**84544**

3 Findings

The research developed in this work aims to present an overview about HEI contributing to publishing journal papers on EER as a perspective on research in this field, and cross relate this data with the institutions that have Centres of Engineering Education and/or Staff Development, and this way are showing that they are working on the improvement of engineering education practice.

3.1 Higher Education Institutions publishing in EER

The Scopus search results showed 160 institutions with 25 or more papers published in journals, since 1970. Cross relating this results with the Times ranking it was possible to identify in this list, 17 of the Top 25 HEI of the ranking. Figure 19 presents the evolution of publications from 1970 to 2016, showing a steady increment and a high increment since 2009.

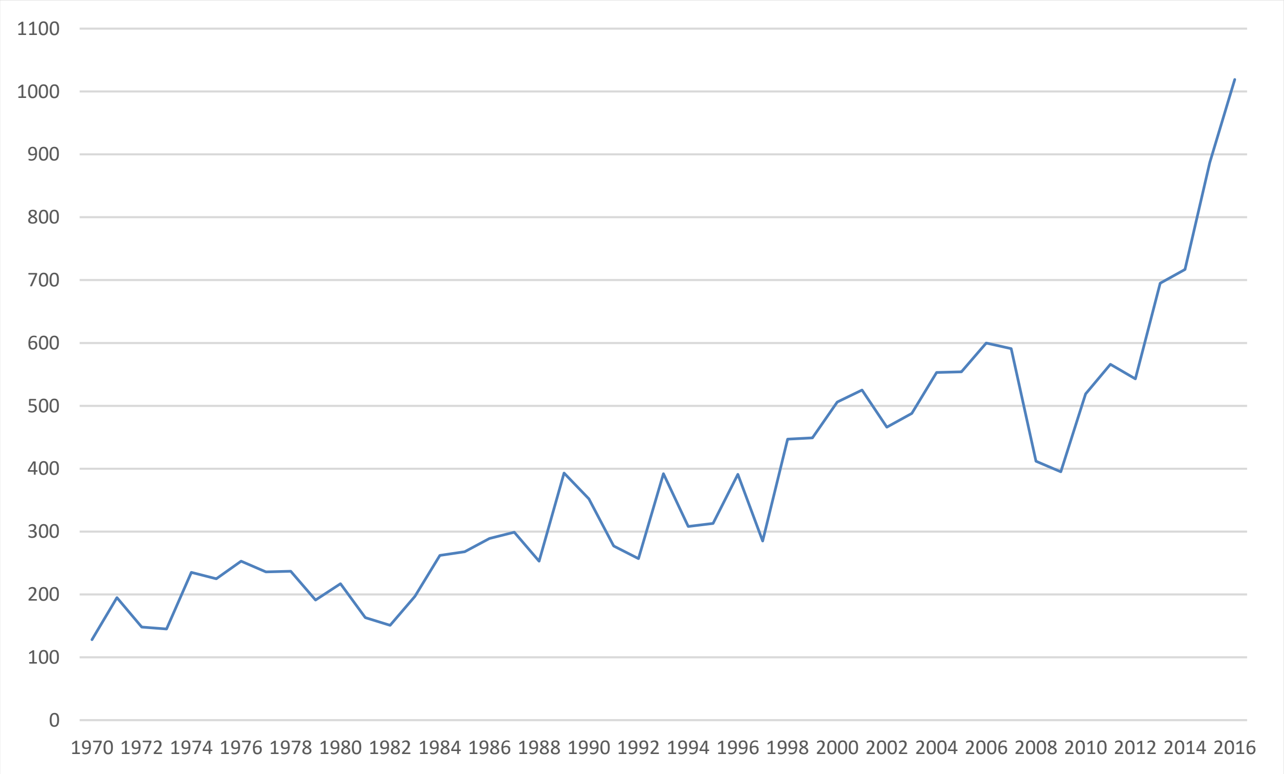

Figure 19: Evolution of the number of publications from 1970 to 2016

Moreover, a selection of the Top 25 bibliometric (step 5 of the methodology) was created and presented in Table 7. In this table it is possible to identify 7 of the Times Top 25. Purdue University is by far the HEI with the highest number of published papers in the EER field. Furthermore, some of the most renowned HEI have been publishing in this area of research since 1970 and are simultaneously being recognised as highly rated institutes in the Times ranking.

Considering that this analysis has a large number of years, a new analysis was made for the last 5 years, since 2012, in order to identify new HEI with a high amount of recent publications. In this new analysis it was possible to identify the following HEI entering in the Top 25 bibliometric:

- Aalborg Universitet
- Utah State University
- University of Ljubljana
- National Taiwan Normal University
- Chalmers University of Technology
- Oregon State University
- Universidad de Salamanca
- Universidad Nacional de Educacion a Distancia

- Queensland University of Technology QUT
- National Taiwan University
- The Royal Institute of Technology KTH
- Universidade do Minho

Table 7: Top 25 HEI with papers published in journals since 1970

#	AFFILIATION	Number of papers	World rank
1	Purdue University	298	70
2	IEEE *	203	
3	Pennsylvania State University	185	13
4	Virginia Polytechnic Institute and State University	163	251
5	Georgia Institute of Technology	144	33
6	University of Texas at Austin	120	50
7	University of Washington Seattle	117	25
8	Massachusetts Institute of Technology	117	5
9	Texas A and M University	112	169
10	North Carolina State University	111	201
11	Arizona State University	109	131
12	Carnegie Mellon University	100	23
13	Stanford University	97	3
14	Universidad Politecnica de Madrid	96	601
15	Iowa State University	88	351
16	University Michigan Ann Arbor	84	21
17	Technion - Israel Institute of Technology	83	301
18	University of Manchester	82	55
19	University of Wisconsin Madison	82	45
20	Delft University of Technology	77	59
21	Missouri University of Science and Technology	72	501
22	Nanyang Technological University	70	54
23	Rensselaer Polytechnic Institute	67	251
24	Loughborough University	66	301
25	Universitat Politecnica de Catalunya	66	401
26	University of Florida	66	134
27	UC Berkeley	66	10

* IEEE is listed as affiliation of authors but is not a HEI.

Going a bit deeper in the analysis of the publications, it was possible to identify the top 10 authors publishing papers related to the term "Engineering Education" in journals indexed in Scopus. This list presents 12 authors in Table 8. Additionally, it was possible to analyse the original education area of these authors, based on a web search developed on January, 1st 2018. Considering the 12 authors' Bachelor or Master degree, there is only one author that has not originally an engineering degree.

Table 8: Top 10 authors with papers published in journals

#	Name	Number of papers	Area (Bachelor or Master degree)
1	Borrego, M.	37	Mechanical Engineering
2	Wald, M.	36	Engineering - Math and physics
3	Dym, C.L.	26	Engineering design
4	Atman, C.J.	25	Industrial Engineering
5	Ohland, M.W.	24	Mechanical Engineering
6	Besterfield-Sacre, M.	23	Industrial Engineering
6	Pudlowski, Z.J.	23	Electrical Engineering
8	Kolmos, A.	22	Social Science and Psychology

9	Felder, R.M.	20	Chemistry Engineering
10	Finelli, C.J.	18	Electrical Engineering
10	Adams, R.S.	18	Mechanical Engineering
10	Case, J.M.	18	Chemical Engineering

3.2 Centres of Engineering Education and/or Staff Development

An analysis of the Centres of Engineering Education and/or Staff Development in the Times Top 25 was developed, in order to understand if the HEI have specific organizational units to improve the engineering education practice. The overall results are presented in Table 9.

It was possible to identify, in every HEI in the Times Top 25 at least one organizational unit related specifically to engineering education (Type 1), or one organizational unit related to staff development (Type 2) or one initiative to develop innovation in learning that is institutionalized in the HEI website (Type 3). It was possible to identify 31 units in the 25 HEI. The analysis of these 31 units, allowed to identify 13 from Type 1, 14 from Type 2, and 4 from Type 3. Additionally, at least 5 of these units are explicitly linked to human Resources management, incorporating processes of career development or staff hiring. Three of these HEI refer to Networking units that involve several HEI, being two of them the same unit.

An analysis of the main information presented in the websites was developed in order to understand the main mission and activities of these units. One of the main characteristics of the mission statements (or general objectives) of these units are to support higher education teachers in improving their teaching effectiveness, in order to improve learning. In this way, teachers can easily access services and training related to teaching different audiences with different profiles. These services and training opportunities give support to designing, planning and delivering classes, and to curricular design or restructuring. Additionally, it helps teachers to improve the way they deal with the teaching – research nexus and with the outreach activities. Some of these units have explicit links with undergraduate students.

Table 9: Centres of Engineering Education or Staff Development in the Times Top 25

Rank	Higher Education Institution	Education support
1	University of Oxford United Kingdom	Training & development https://www.ox.ac.uk/staff/working_at_oxford/training_development?wssl=1
2	California Institute of Technology United States	Caltech Center for Teaching, Learning, & Outreach (CTLO) https://www.ctlo.caltech.edu/
3	Stanford University United States	Cardinal at work https://cardinalatwork.stanford.edu/learn-grow
4	University of Cambridge United Kingdom	CETE Center of Excellence for Technology Education (network) http://www.cete-net.com/home/?no_cache=1
5	MIT United States	Teaching and Learning Lab (http://tll.mit.edu/about/who-we-are-and-what-we-do) Communication Lab (http://mitcommlab.mit.edu/about-us/)
6	Harvard University United States	Office of Faculty Development & Diversity https://faculty.harvard.edu/about
7	Princeton University United States	Keller Center for Innovation in Engineering Education https://kellercenter.princeton.edu/
8	Imperial College London United Kingdom	Education and teaching support https://www.imperial.ac.uk/engineering/staff/education-and-teaching-support/
9	ETH Zurich Switzerland	Educational Development and Technology (LET) https://www.ethz.ch/en/the-eth-zurich/organisation/departments/educational-development-and-technology.html
10	University of California, Berkeley United States	Center for Teaching & Learning http://teaching.berkeley.edu/
10	University of Chicago United States	Engineering Makerspace (http://coemakerspace.uic.edu/) UIC Innovation Center (http://innovationcenter.uic.edu/wordpress/?page_id=475)
12	Yale University United States	Center for the Integration of Research, Teaching, and Learning (CIRTL) (network) (https://www.cirtl.net/) Center for Engineering Innovation and Design (CEID) (http://ceid.yale.edu/about-1/#courses)
13	University of Pennsylvania United States	Leonhard Center for Enhancement of Engineering Education http://www.engr.psu.edu/leonhardcenter/

Rank	Higher Education Institution	Education support
14	University of California, Los Angeles United States	Human resources - Training and Development https://www.chr.ucla.edu/training-and-development
15	University College London United Kingdom	UCL Centre for Engineering Education http://www.engineering.ucl.ac.uk/centre-for-engineering-education/
16	Columbia University United States	Center for the Integration of Research, Teaching, and Learning (CIRTL) (network) https://www.cirtl.net/
17	Johns Hopkins University United States	Center for Educational Resources (CER) http://cer.jhu.edu/about
18	Duke University United States	Human resources https://hr.duke.edu/training/course-offerings
19	Cornell University United States	James McCormick Family Engineering Teaching Excellence Institute (METEI) (https://www.engineering.cornell.edu/academics/teaching/teaching_excellence/) Center for Teaching Excellence (CTE) (https://www.cte.cornell.edu/about/index.html)
20	Northwestern University United States	Northwestern Center for Engineering Education Research (NCEER) http://www.mccormick.northwestern.edu/research/engineering-education-research-center/
21	University of Michigan United States	Center for Research on Learning and Teaching in Engineering (CRLT-Engin) https://crlte.engin.umich.edu/
22	University of Toronto Canada	Education Technology Office (ETO) (http://edtech.engineering.utoronto.ca/) Centre for Teaching Support & Innovation (CTSI) (http://teaching.utoronto.ca/)
23	Carnegie Mellon University United States	Center for Faculty Success (CFS) https://engineering.cmu.edu/faculty-staff/professional-development/center-faculty-success/index.html
24	National University of Singapore Singapore	Centre for Development of Teaching and Learning (CDTL) http://www.cdtl.nus.edu.sg/welcome-to-cdtl.htm
25	London School of Economics and Political Science United Kingdom	Academic and Professional Development Division (https://info.lse.ac.uk/Staff/Divisions/Academic-and-Professional-Development-Division) Teaching and Learning Centre (https://info.lse.ac.uk/Staff/Divisions/Teaching-and-Learning-Centre/Teaching-and-Learning-Centre)

4 Concluding remarks

The importance of education in engineering HEI can be considered indisputable. Nevertheless, the real meaning of this importance is another question. Many engineering HEI consider the "teaching" (education) role of their staff much less important than the "research" role. This relative importance could be analysed in several different ways, namely by staff assessment procedures and criteria, hiring or career development processes, or organizational culture. In this paper the authors analysed data that show one perspective about the importance that some of the most renowned HEI give to the education role. This analysis was made with two angles, one centred in the existence of units that give support to the teaching activities and other that analysed the research that is being made by the HEI staff that is explicitly related to Engineering Education. This analysis is pragmatic in the sense that shows the "energy" that some of the most renowned HEI and their staff put in these activities.

It was possible to identify that all Times Top 25 HEI have units dedicated to engineering education or staff development. Some of these units explicitly refer research in "Engineering Education" (EER) as being part of their mission or activities. Part of these Times Top 25 HEI were also identified in the analysis of the institutions with more journal papers published with the topic "Engineering Education". In future work, regional analysis could give a more worldwide perspective of these type of units, avoiding to present a larger amount of units from specific parts of the world.

The authors support the idea that both approaches, organizational units that give support to Engineering Education practice and Engineering Education Research, are important for improvement of Engineering Education. This idea is supported by the fact that most of the highly recognized engineering HEI show results on these two paths. Thus, one can consider that these can be seen as interconnected paths with intertwining results. Improving the practice of Engineering Education, also improve the training of new engineers and hopefully reduce the gap between education and professional activity. To attain this improvement, engineering teachers must be close to engineering practice. Being close to the engineering practice creates opportunities to improve research about the engineering practice. In order to continuously improve Engineering Education practice, engineering teachers should be involved in scholarly research about their own practice. In conclusion, a virtuous cycle of education, practice and research, simultaneously about engineering and Engineering Education can contribute significantly to the improvement of engineering schools.

5 Acknowledgements

This work has been partially supported by projects COMPETE-POCI-01-0145-FEDER-007043 and FCT-UID-CEC-00319-2013, from Portugal.

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