

# Engineers' education in digital era

## *Formação de engenheiros na era digital*

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### Abstract

The Fourth Industrial Revolution has already taken around the world. Decision taking at industries is more and more dependent on new technologies and processes, which demand updating and adjustment of the engineering education. Through a systematized literature revision, this article aims to search, select and prioritize bibliographic sources which reflect relevant initiatives that may work as a reference for engineering bachelor's degree courses. 50 most relevant articles were selected and analyzed from 4,333 articles published in the Scopus database. The results show the 10 main authors, the 9 main journals and the 10 main institutions among the 50 most relevant articles, as references in the analyzed sample. Regarding aspects for the improvement of engineers education, one can highlight PBL (Project-Based Learning), Competency-Based Education and focus on holistic education. This research may encourage reflection, awareness and improvement by the ones interested in the study of engineers' education, by integrating market demand, learners' expectations and academic excellence, in order to contribute to the growth of scientific and practical knowledge and of society technological development.

**Keywords:** Project-Based Learning. Flipped Classroom. Competency-Based Education. Holistic education. Engineering education.

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## Resumo

A Quarta Revolução Industrial já deu a volta ao mundo. A tomada de decisão nas indústrias está cada vez mais dependente de novas tecnologias e processos, que exigem atualização e adequação da formação em engenharia. Por meio de uma revisão sistematizada da literatura, este artigo tem como objetivo buscar, selecionar e priorizar fontes bibliográficas que reflitam iniciativas relevantes que possam servir de referência para cursos de graduação em engenharia. Os 50 artigos mais relevantes foram selecionados e analisados a partir de 4.333 artigos publicados na base de dados Scopus. Os resultados mostram os 10 autores principais, os 9 periódicos principais e as 10 instituições principais entre os 50 artigos mais relevantes, como referências na amostra analisada. Em relação aos aspectos para a melhoria da formação de engenheiros, pode-se destacar o PBL (Aprendizagem Baseada em Projetos), a Educação por Competências e o foco na educação holística. Esta pesquisa pode estimular a reflexão, a conscientização e o aprimoramento dos interessados no estudo da formação de engenheiros, integrando a demanda do mercado, as expectativas dos alunos e a excelência acadêmica, de forma a contribuir para o crescimento do conhecimento científico e prático e do desenvolvimento tecnológico da sociedade.

**Palavras-chave:** Aprendizagem baseada em projetos. Sala de aula invertida. Educação baseada em competências. Educação holística. Educação em engenharia.

## 1 Introduction

The current days reflect a technological revolution, the Fourth Industrial Revolution or Industry 4.0, mainly triggered by the internet used in industrial processes, as an objective to ensure connectivity and integration between items that are daily applied in companies such as machines, software and database. Over the course of time, material and digital worlds have merged through intelligent devices which are compatible with one another, interact and react to the external environment such as Big Data; Autonomous Robots; Simulation; Systems Integration; Internet of Things (IoT); Cybernetics Safety; Cloud; Additive Manufacturing (3D Printing) and Augmented Reality (SILVA, 2019).

According to Costa (2017), the impact of Industry 4.0 is beyond simple digitization. It has been evolving through a much more complex innovative way based on the combination of multiple technologies, which will require companies to rethink how they manage their businesses and processes. Digital transformation projects redesign their organizational structure, modus operandi and related products/services production processes, by applying technology to digitalize the essence of its mechanics in at least one of these pillars (BEZERRA; SANTOS, 2019).

Engineers are professionals who deal with the Digital Transformation and Industry 4.0 scenario. Thus, the following questions are addressed: How should contemporary engineers be educated? Which studies or research centers can contribute to engineers education adjustment?

The objective of this article is to identify methodological practices and initiatives, based on the analysis of sample articles obtained through the search tool of the Scopus database systematized method. Secondly, the article presents analysis of bibliometric data related to the search results, which allow that references are made regarding authors, articles and research centers that have made efforts to improve the education of engineers at the digital era.

It's necessary to think about teachers preparation infrastructure and interdisciplinary curriculum at Higher Education Institutions. It is expected that a reflection stimulated by this paper contributes to the development and training of professionals, both teachers and learners, through updating, creativity, and commitment with continuous learning, which will impact on engineers education at times of transformation and revolution in environments where engineering is applied.

Perdigones et al. (2014) evidence differences between what competences agricultural employers require of graduates and the competences they acquire along their engineering degree courses. Valiulis (2003) points the need of the Engineering Education attend the employers' demands not only for fundamental knowledge the students acquire during their studies, but also for multicultural qualifications, competencies in social, economical and ecological matters.

## 2 Literature review - Engineers' education

The Literature Review (LR) comprises methods, characteristics, competences or constructs obtained from a qualitative analysis of the content of the 50 most relevant articles, according to Scopus, among the 4,333 obtained from the systematized search. The LR is based on Project-Based Learning, Competency-Based Teaching, Holistic Education, Project Management, Simulation, and Flipped Classroom Learning articles. The ordering of the RL constructs is related to the quantity of articles obtained in the analysed sample.

### 2.1 Project Based Learning

According to Sony (2020), Industry 4.0 will lead to an interaction between human beings and cybernetic systems through specialized ways, by constituting a whole made of social and technical spheres, in the search of common objectives. Similar perspectives stimulate the emergence of contexts such as Conceiving - Designing - Implementing - Operating (CDIO), that is, a model of open architecture, an innovative educational structure, adaptable to engineering programs, by respecting their specific needs and realities, with assessment based on results, scientifically based, with the aim of developing individual and interpersonal skills, as well as the capacity to conceive, design, implement, and operate engineering systems (EDSTRÖM, 2014).

The CDIO method proposes curriculum innovation, through Problem-Based Learning (PBL), by solving problems, when students learn how to solve them and acquire competence to solve similar ones. Problem Based Learning (PBL) is a method in which real-world problems are used as a vehicle to promote the learning of concepts and principles (LUNEV; PETROVA; ZARIPOVA, 2013). In addition to PBL, Extracurricular Activities, Academic Exchange Programs, Entrepreneurship, and Remote Teaching are characteristic items in CDIO programs. The method aims to aggregate technical capacities and skills to steer the development of solutions that are economically, socially, and environmentally acceptable to technical problems (EDSTRÖM, 2014).

Caridade et al. (2018) utilize Project-Based Learning in Calculus courses for engineers in Coimbra and Salamanca, by applying mathematical softwares for estimating the area of the Iberian Peninsula, so that experiences are evaluated as enriched ones by the students. Cocota, D'Angelo and de Barros Monteiro (2015) apply the Project-Based Learning for the development of transversal skills in engineering multidisciplinary education. During 2 years, the Automation and Control as well as the Mechanical Engineering students of the Federal University of Ouro Preto developed a robot. There was a low degree of abandonment and results from assessments prove the efficacy of the method through the engagement and motivation of the students.

Sanchez-Azqueta et al. (2016) describe experiences with micro and nanoelectromechanical systems learning, through the adaptation of fabrication phases to the teaching environment, from design per software, until experimental characterization, after fabrication, by stimulating the learning autonomy, collaborative work, in a realistic environment. Ortiz et al. (2017) describe a study on C programming language in the assembly of robots, by increasing the interest, satisfaction, confidence, and motivation of students. Mazorra et al. (2016) apply PBL in 8 subjects at the master degree course in Technology for Human Development, at Madrid University. Students work on realistic, multidisciplinary projects, under the coordination of teachers, by developing competences in communication, team work, sociotechnical evaluation of alternative.

Macho-Stadler and Jesús Elejalde-García (2013) analyse the results of using the problem-based learning (PBL) method in the telecommunication engineering degree programme. From an instructors' perspective, PBL strengths students' attitude and increased interactions in classes. Miranda et al. (2020) apply questionnaires and interviews to analyse the implementation of a project-based learning with satisfactory results.

## 2.2 Competency-based Education

Competency-based Education is highlighted in studies about engineers higher education and also postgraduate courses, as established by García et al. (2016) who study by comparing competency-based Master programs, based on the perspective of teachers from the Polytechnic University of Catalonia and the University of Barcelona. Gonzalez et al. (2018) present a competency evaluation methodology of students, real time, through Socratic application, at the Industrial Engineering School and at the Merida University Center, with outcomes which prove the improvement of competences and skills, in addition to students' increase of interest in the program content as well as in their collaborative attitude. Lunev, Petrova and Zaripova (2013) study similarity among the competencies developed in Russian universities and European universities, and the results indicate possible convergence among universities all over the world.

While Lopez (2016) describe a set of motivating actions, considers the learning evaluation of outcomes and competences, by using laboratories, in a subject of the Engineering Polytechnic School, in Gijon, Spain. Olmedo-Torre and Martínez (2018) develop projects of voluntary activities for the development of autonomous learning competences in Graphic Expression, a subject of the Engineering School of Barcelona, which result in the exchange of

knowledge among teachers of Spatial Geometry and application in different subjects with positive evaluation from students.

Olmedo-Torre et al. (2018) analyse the main generic competences acquired at the Polytechnic University of Catalonia, according to students, by highlighting the autonomous learning, effective use of information resources, team work, good spoken and written communication. Carracedo et al. (2018) proposes a strategic map for competency development in sustainability, by involving 5 engineering courses, 10 universities and subsidized by a P&D Spanish program. The map of competences is vital for the definition of qualification of teachers and students at engineering courses.

Cortés, Pellicer and Catalá (2012) define an engineering curricular structure, considering the education and competency in occupational risks prevention, through researches with specialists, whose results recommend engineering higher education. Bernasiuk, Bacelar and Streck (2000) investigate and prove the importance of Extracurricular Activities in the qualification and development of competences of Medical Physics students, at PUCRS, Brazil.

Valentine et al. (2019) indicate that competency and skills related to creativity are depreciated in engineering courses, although they are important in engineers' professional lives.

## 2.3 Holistic Education

For an engineer, holistic education means to aggregate new knowledge and skills to basic technical competences. This professional may live in distinct communities and cultures which live and solve their everyday problems. Engineers should be able to communicate; know how to work with multidisciplinary teams; be aware of social, ecological, and ethical implications involved in the engineering project; speak more than one language; be willing to work in any part of the world (Elmor Filho, 2019, p. 26). Durrans, Whale and Calais (2020) propose a curriculum structure for Renewable Energy Engineering, at Murdoch University, in Australia, based on recommendations made by the industry and on pedagogical research, which strengthen engineers sustainable and holistic competency education.

Studies indicate changes that artificial intelligence will cause on engineers' education. Dyer (2019) shows that routines that have been performed by engineers up to then have been carried out by technicians and technical professionals, with the help of IT or AI systems with machine learning algorithm. Alternatives to incorporate education in the style of Science, Technology, Engineering, Automation, and Mathematics (STEAM) in engineering education courses are proposals based on lessons learned. The result is a multidisciplinary structure, combined with pedagogical practices, Art, and Design, with focus on engineering holistic education. Sánchez Carracedo et al. (2018) present a model to develop holistic professional competences in Science, Technology, Engineering, and Mathematics courses (STEM), whose evaluation is obtained from 4 sources: the courses' students, new graduates, alumni, and IES ranking answered by employers.

Schäfer and Richards (2007) coordinate an interdisciplinary design project that involve sustainable membrane technology with renewable energy to provide water for communities in developing countries, by voluntary participation of the students. The acquiring

of technical skills, teamwork and interpersonal skills, project management and confidence in interacting with non-engineers are some of the results.

## 2.4 Project Management

It is noticed that there is a gap in the education of engineers and a strong progress in interdisciplinarity. Curriculum frameworks have been aligned with this purpose. An engineering project depend on specialists in other sectors, otherwise the completion of the project is compromised. Interdisciplinarity gains importance through proven studies such as those by De Los Ríos-Carmenado, López and García (2015) that propose a methodology for project management qualification, in engineering higher education, through Project-Based Learning, with focus on professional competences for the International Project Management Association (IPMA) certification. The IPMA certification, evaluation of competences, focus on reality, dynamism, and research applied to teaching, are factors of success and were shown by outcomes of the methodology evaluation. While Falcone et al. (2014) propose the development of transversal competences and multidisciplinary skills in final papers of higher education and master degree courses, to be assembled according to real demands from industries and corporations.

González-Marcos et al. (2016) innovate project management teaching with a collaborative model based on projects, com transversality between different engineering courses, with focus on teamwork and communication competences; and skills such as leadership, negotiation and team management. Badawy (1995) proposes an educational strategy for the technology management career development and highlights the contribution of MBA and MEM (Master Engineering Management) courses in the teaching of management concepts, thus he indicates a deficiency to prepare students to deal with technology management specificity and complexity problems.

## 2.5 Simulation

Simulation knowledge is relevant to engineers and can be applied to the analysis of physical phenomena or industrial processes as substantiated by the research by Barbero and García García (2011) who utilize the learning experimental method, evaluate outcomes, and restructure the CAD 3D teaching program, including simulation and kinematic analysis of industrial assembly processes, for industrial engineering, at Spanish universities. Rodríguez-Martín and Rodríguez-González (2019) propose a tridimensional methodology for weld inspection qualification, at Mechanical Engineering course, by developing competence in the specific area, approved by the students.

Rodríguez-Martín et al. (2019) apply simulation with fluids in Mechanical, Electrical, and Electronic Engineering courses, with good acceptance in terms of usability, learning, motivation and satisfaction. While Turker, Coskun and Mertayak (2016) apply simulation in structural dynamics.

## 2.6 Flipped Classroom Learning

According to Bergmann (2016, p. 11), "flipped classroom learning" is a method through which what is done traditionally in class, is performed at home; and what is done as homework, is carried out in class. This methodology has appealed to students, because they can adjust tasks demands with available time so that these can be accomplished, which helps students during their traineeship time, for example.

These reflections make students change patterns, because they take advantage of laboratories for the application of theory into practice, however, difficulties are detected such as those investigated by Perez-Sanchez and Morais (2016) who study comparatively the difficulties of learning and teaching Data Structures in the Computation Engineering course, at La Coruña and Portugal Universities.

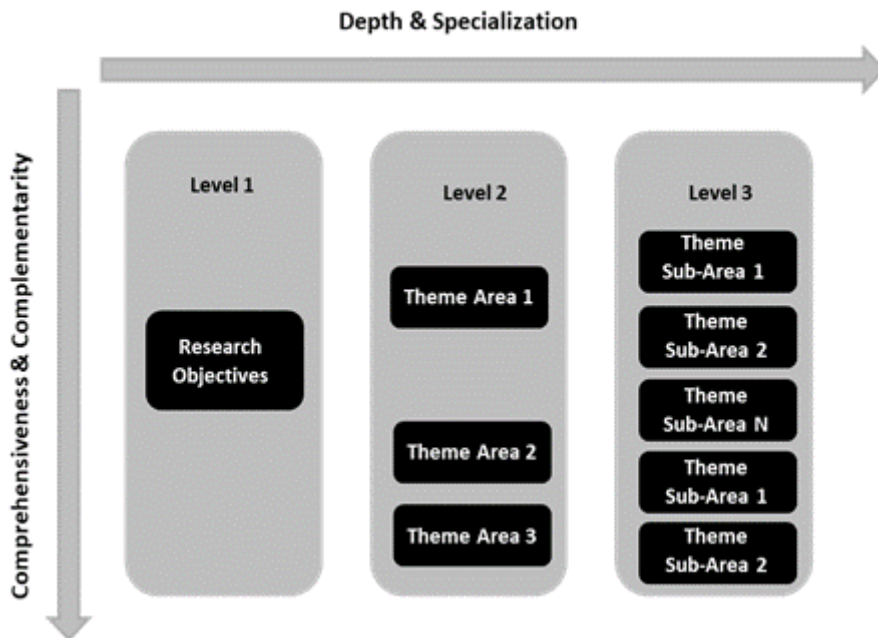
Flipped classroom learning can also be applied remotely or in Distance Learning formats, which enable students to watch classes taught by teachers from other states, countries with the aim of integrating students in regional and international realities with regard to the subject or topic, in a global scenario, or yet as Fita et al. (2016) propose, through a simultaneous e-learning environment for improving the remote interaction and integration between teachers and students, of Telecommunications, Agricultural, and Computational Science Engineering courses, at Polytechnic University of Valencia.

Events that are not interesting, such as those studied by Oo, Li and Zhang (2018) who relate the personal interest to the career opportunities according to the level of the course appeal can be dealt with a teaching-learning strategy different from the one applied up until then. When a strategy is applied in class, it is implied that there is a belief that the student builds his/her knowledge in a certain way. When someone chooses a work strategy to steer the teaching-learning process, it is said that it shall express the most generative way to promote learning (OLIVEIRA, 2019).

## 3 Methodology

The definition stage of "research concepts" is fundamental for the research strategy. Farias Filho et al. (2018) proposes a bibliographic research strategy, through a keywords concept tree shown in the figure.

Figure 1 – Keywords Concept Tree



Source: Farias Filho, 2018.

Keywords are interconnected, with Boolean search logic, through connectors “and” and “or”, which resulted in the following Boolean combination:

TITLE-ABS-KEY (engineer\* AND ((learn\* OR teach\* OR graduat\* OR degree OR instruct\*) AND (activit\* OR competenc\* OR innovat\* OR strateg\* OR benchmark\*))) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (EXACTKEYWORD, "Engineering Education") OR LIMIT-TO (EXACTKEYWORD, "Teaching") OR LIMIT-TO (EXACTKEYWORD, "Education") OR LIMIT-TO (EXACTKEYWORD, "Learning Systems") OR LIMIT-TO (EXACTKEYWORD, "E-learning") OR LIMIT-TO (EXACTKEYWORD, "Innovation"))

The total number of articles was 4,333. These were sorted by descending "relevance". Thus, the sample of the 50 most relevant articles was selected and exported to EndNote, where it was cataloged.

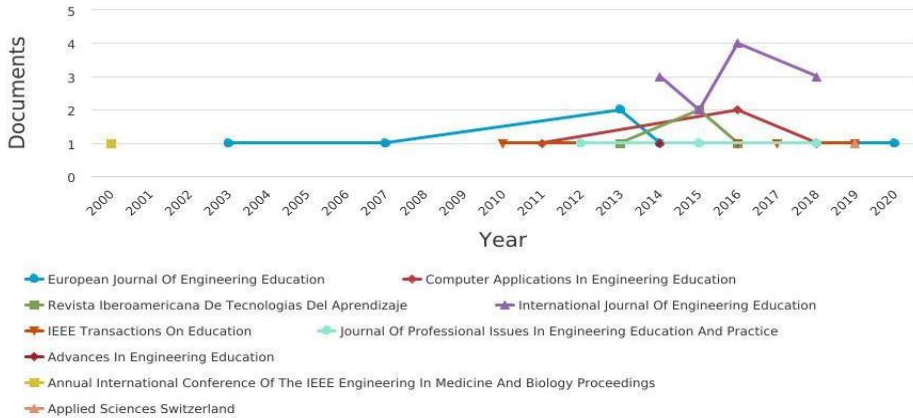
## 4 Analysis and discussions

In the sample of the 50 most relevant articles, Scopus records 9 most relevant journals, with their respective publications, as following: European Journal Of Engineering Education:



"6"; Revista Iberoamericana De Tecnologias Del Aprendizaje: "4"; IEEE Transactions On Education: "2"; International Journal Of Engineering Education: "12"; Advances In Engineering Education: "1"; Journal Of Professional Issues In Engineering Education And Practice: "4"; Annual International Conference Of The IEEE Engineering In Medicine And Biology Proceedings: "1"; Applied Sciences Switzerland: "1"; Computer Applications In Engineering Education: "4".

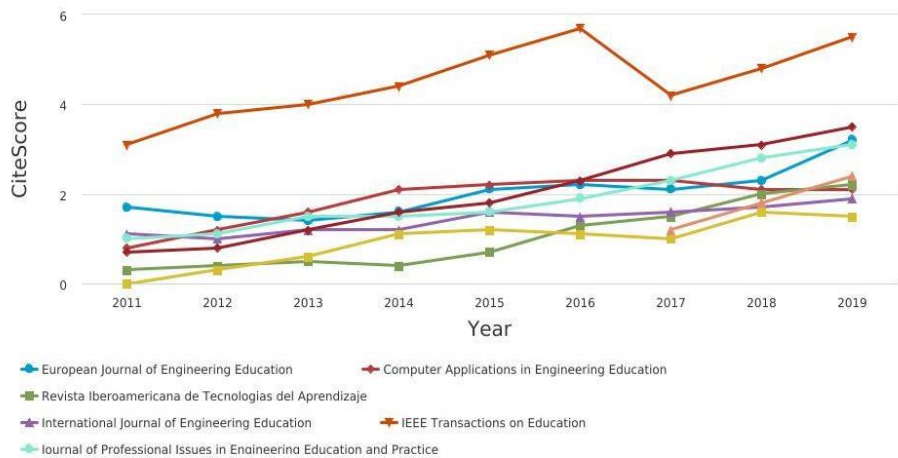
Figure 2 – Number of articles per journal



Source: (SCOPUS, 2021).

Figure 3 illustrates the score graph for the CiteScore indicator, which measures the importance of a journal in relation to the number of citations used by another researcher. Through this metric it is possible to observe the importance and quality of the publications of a given journal. Looking at the graph, it is possible to see the evolution of the journals over the years, with the highlights being the journals IEEE Transactions on Education, Computer Applications in Engineering Education and European Journal of Engineering Education.

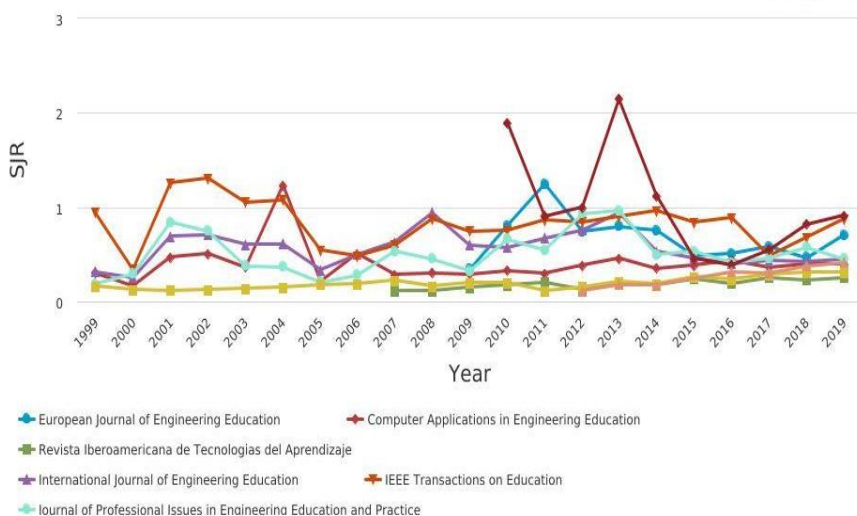
Figure 3 – CiteScore publication by year



Source: (SCOPUS, 2021).

The SCImago Journal Rank (SJR) represents a metric of the scientific influence of journals by the number of weighted citations received and the importance of the journals of origin of these citations. As shown in figure 4, Computer Applications in Engineering Education, IEE Transactions on Education and European Journal of Engineering Education are featured in the SJR score in recent years.

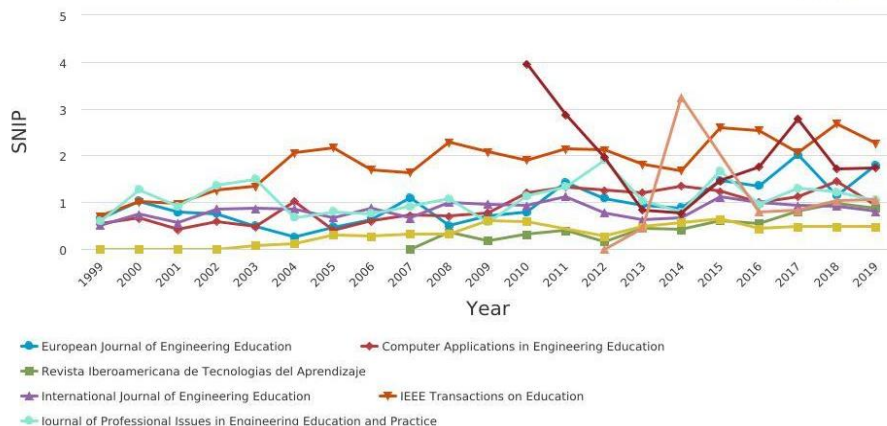
Figure 4 – SCImago journal rank by year



Source: (SCOPUS, 2021).

Figure 5 below shows the score graph for the SNIP indicator, which is a metric that measures the impact of the citation in different areas of knowledge. Once again, Computer Applications in Engineering Education, IEE Transactions on Education and European Journal of Engineering Education stand out.

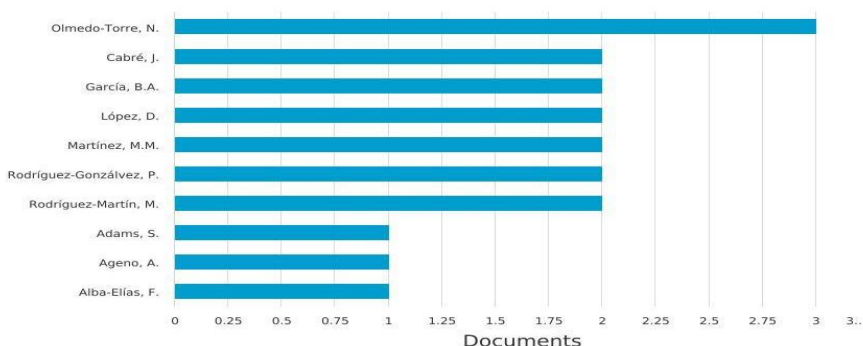
Figure 5 – Source normalized impact per paper by year



Source: (SCOPUS, 2021).

The amount of scientific production per author, taken from the Scopus database, is shown in the graph below, highlighting the authors who most published articles in the sample of the 50 most relevant articles, being: Olmedo-Torre, N.: "3"; Cabré, J.: "2"; García, B. A.: "2"; López, D.: "2"; Martínez, M. M.: "2"; Rodríguez-Gonzálvez, P.: "2"; Rodríguez-Martín, M.: "2"; Adams, S.: "1"; Ageno, A.: "1"; Alba-Eliás, F.: "1".

Figure 6 – Documents by author

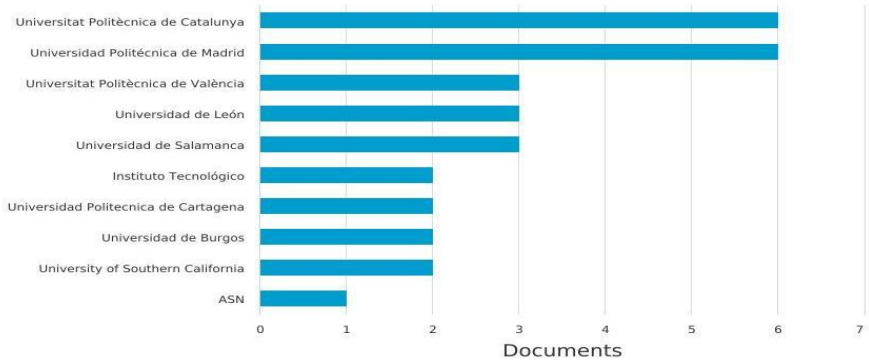


Source: (SCOPUS, 2021).

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The institutions with more affiliated authors are: Universitat Politècnica de Catalunya,"6"; Universidad Politècnica de Madrid,"6"; Universitat Politècnica de València,"3"; Universidad de León,"3"; Universidad de Salamanca,"3"; Instituto Tecnológico,"2"; Universidad Politècnica de Cartagena,"2"; Universidad de Burgos,"2"; University of Southern California,"2"; ASN,"1".

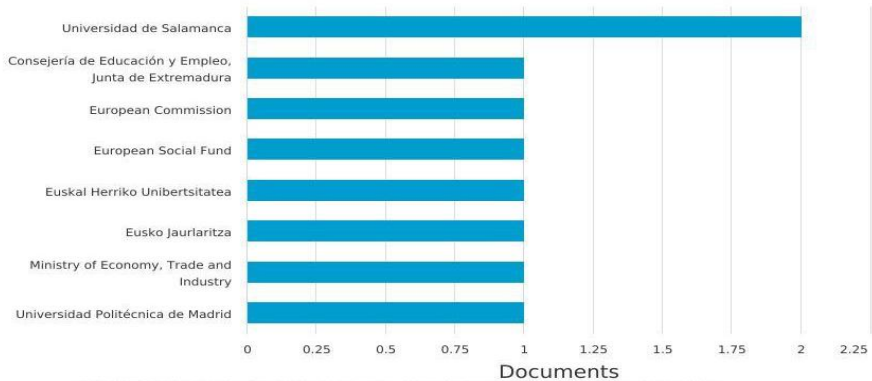
Figure 7 – Documents by affiliation



Source: (SCOPUS, 2021).

Figure 8 below shows the Documents by funding sponsor, being: Universidad de Salamanca: "2"; Consejería de Educación y Empleo. Junta de Extremadura: "1"; European Commission: "1"; European Social Fund: "1"; Euskal Herriko Unibertsitatea: "1"; Eusko Jauriaritza: "1"; Ministry of Economy, Trade and Industry: "1"; Universidad Politècnica de Madrid: "1".

Figure 8 – Documents by funding sponsor



Source: (SCOPUS, 2021).

## 5 Conclusions

It is noticeable that there is a lack of guidelines for innovation management at the age of digital transformation, specifically in engineering teaching. There is a need of schools which teach practical, emotional skills to their students and, mainly, teach them how to learn. There is a lack of disruptive learning environments, where professionals are educated with competences demanded by the current market context. In a world of constant change, the ability of adapting oneself is the most important of all. More than ever, the one who has this ability as the most developed one will survive. Collaborative and better qualified engineers to work in a competitive world with a diverse spectrum of needs - this is the reality nowadays.

It becomes imperative to provide training to the body of teachers in new teaching and learning experiences and active methodologies focusing on teaching-learning processes that prioritize active participation of learners and teachers in the knowledge construction. While the teacher (tutor) uses problematization as a strategy, the learner has the freedom and autonomy; such relation allows the establishment of process and formative evaluation methods. The learning objectives are established based on the question: What is the complete set of knowledge, skills, abilities and attitudes engineering students should have when finishing higher education and in which degree of proficiency?

The objective of this research to identify methodological practices and initiatives by means of a systematized method is shown in the Literature Review and Methodology sections; while bibliometric data of articles from the analysed sample, which allow the identification of authors from journals and research centers that have been striving to improve engineers education at digital transformation era, are in the Analysis and Discussions section.

With research limitations it is possible to identify the bibliographic basis of the research with the 50 most relevant articles, according to Scopus database. Therefore, in future studies, it is recommended an increase of analysed articles, in other scientific databases, which will allow comparative analysis among research samples.

As a practical implication of the research, one can indicate the possibility of adjustments in engineering higher education Courses Pedagogical Plans (CPP), which would make them more suitable to market's and students' demands. Society will benefit the most from pedagogical and methodological adjustments in engineering higher education courses.

The research outcomes comprises data and objective references of authors and institutions, in addition to the most common practices worldwide for the improvement of engineering education outcomes. Such a set of information is relevant to those who are interested in the topic, such as researchers, faculty members, independent professionals, employers, legislators and regulators.

## Data availability

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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