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Abstract	Design Thinking not only is a well-known technique for user-oriented product design, but also is an education technique in Higher Education. Design thinking is increasingly used as an innovative educational tool to promote in engineering student transversal skills as critical thinking, creativity, and teamwork. However, despite its popularity, the teaching community has implemented it in many different ways focusing on specific aspects without taking in notice of previous experiences. The aim of this work is to analyze the literature published about Design Thinking experience in Engineering Education through a systematic literature review. Our conclusions will contribute to this educational area pointing the state of the art and the future lines of this educational methodology.
Keywords (separated by '-')	Engineering - Education - Design thinking - Systematic literature review

Design Thinking (DT) in Engineering Education (EE): A Systematic Literature Review (SLT)

E. Acebo, J. A. Miguel-Dávila, and L. Herrera

Abstract Design Thinking not only is a well-known technique for user-oriented product design, but also is an education technique in Higher Education. Design thinking is increasingly used as an innovative educational tool to promote in engineering student transversal skills as critical thinking, creativity, and teamwork. However, despite its popularity, the teaching community has implemented it in many different ways focusing on specific aspects without taking in notice of previous experiences. The aim of this work is to analyze the literature published about Design Thinking experience in Engineering Education through a systematic literature review. Our conclusions will contribute to this educational area pointing the state of the art and the future lines of this educational methodology.

Keywords Engineering · Education · Design thinking · Systematic literature review

1 Introduction

Nowadays, modern society is facing huge techno-economic and social changes leading to new forms of organization. Due to this challenge, Higher Education is required to implement new teaching methodologies, directed toward developing in students a set of skills necessary for performing properly in this new paradigm. These new skills which have to be promoted include creativity, teamwork, critical thinking, and the ability to face complex problems. These skills will be, even more

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so than theoretical knowledge, what will define the position of students in the future labor market. The educational community has introduced different methodologies attempting to empower these skills. One stands out for its resounding success among all, known as Design Thinking.

The design thinking (DT) method has become popular among teachers based on its results at Stanford University [3]. However, despite its popularity, there is a weak point that prevents its utilization as the main method: it does not have a stable application framework. Every teacher tries to change some essential aspects to differentiate it from previous ones. This is very frequent in young techniques, but after ten years of popularization it is time to establish a framework for it in order to create a solid base with which to move forward.

Therefore, this paper aims to address this problem by analyzing the most important applications of Design Thinking in Education, continuing the work carried out by Serrano et al. [12], and developing Engineering Education through a Systematic Literature Review that will answer the following main questions:

- What are the leading educational areas in which DT has been applied?
- Why has DT gained relevance in engineering education?
- What results have been obtained from its application in engineering education?
- What are the recommendations and main future lines of research obtained from experiences already carried out?

2 Methodology

A systematic literature review (SLR) is originally from the field of Health Sciences [9, 15] and is based on the application of a set of reproducible protocols in a database. This method allows researchers to obtain greater objectivity and transparency, as well as achieving iterability in the revision of any topic. It differs from the narrative literature review, which is guided by the investigator's interests. SLR consists of combining a comprehensive database with criteria of inclusion, exclusion, and specific classification. To define the scope of the review, there should be enough flexibility to allow originality but enough structure to avoid any bias in the research results. According to Tranfield et al. [15], a systematic literature review is composed of three phases: Planning of the review, Conduct of the review, and Analysis of the results.

In the planning phase, we defined the database used as a source of information and fundamental questions of the research. The database used was the ISI Web of Science, which is one of the most complete databases for all areas of knowledge.

First, an initial search was made with all the documents that could be related to the concept of Design Thinking during the period 1987–2018. The range of more than 30 years analyzes the evolution of this method and its teaching applications. Establishing the beginning of the period in 1987 was not random. In this year Peter Rowe [11] published his book, entitled "Design Thinking", which named the concept as it is nowadays known.

So, after analyzing the most relevant published papers, a search protocol was implemented. First, we established all the journal articles containing the concept of "Design Thinking" in "Title" and/or "Abstract" as inclusion criteria. Second, we established our exclusion criteria, selecting only scientific journal articles whose core was related to education. The science indexes used in this research were Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), and the recently created Emerging Sources Citation Index (ESCI). The first search (inclusion criteria) yielded 221 scientific articles about Design Thinking, which were reduced to 83 articles after applying the exclusion criteria. This reduced group of papers was analyzed in-depth in the next phase.

3 Results

To analyze the papers filtered by the inclusion and exclusion criteria, we studied their formal aspects (date of publication, journal, and educational area), as well as the content of the papers (nature of the experiment, analysis of the results, and recommendations). In this part, the analysis focused on those related to Engineering Education.

The analysis of publication dates revealed the almost foundational importance of the work of Brown [3] as pointed out by Johansson-Skoldberg et al. [5]. This document settled the beginning of DT's popularity worldwide. In addition, it can be pointed out that although the number of papers on DT has decreased in the last two years, their application in education has remained stable (Fig. 1).

Table 1 shows the journals in which studies on DT methodology were published. Some of the most-used journals for researchers in Engineering were *Design Studies* (position 25th of 86 in the Web of Knowledge category *Engineering Multidisciplinary*), *Journal of Engineering Design* (position 29th of 86 in *Engineering Multidisciplinary*), and *International Journal of Technology and Design Education* (position 41th of 86 in *Engineering Multidisciplinary*).

Table 1 also shows that this subject matter has been published in high-impact journals in other fields, such as *Harvard Business Review* (25 out of 210 in the Management category) and *Academy of Management Learning & Education* (18 out of 239 in the Education and Educational Research category). The importance of those journals focused on Education had an obvious significant weight in the articles selected since Design Thinking in Education was analyzed, but its weight would have been reduced if all articles about DT had been considered.

Continuing with the analysis of the disciplines interested in this methodology, we classified the literature according to the participants' educational areas or their theoretical orientation. Table 2 shows the results of this analysis. This classification revealed a fundamental characteristic of DT, which is its tendency to set up multidisciplinary teams in which different profiles are combined. This category came first (16.87%), followed by Management (14.46%), Engineering (13.25%), and Design

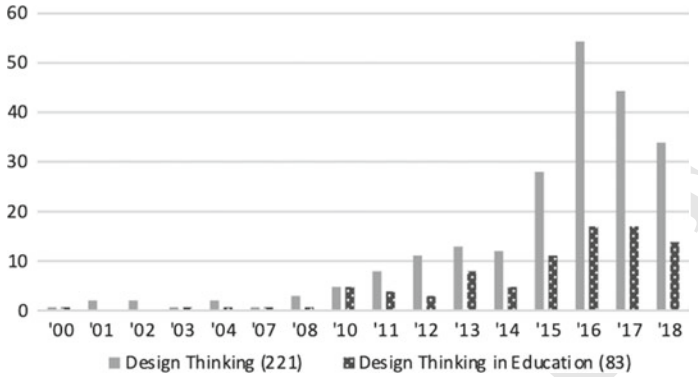

Fig. 1 Articles about design thinking (DT) and design thinking in education (DTE)

Table 1 Journals in which the articles about design thinking in education were published

Journal	Number of publications	Percentage of 83
Design Studies	6	6,70%
Thinking Skills and Creativity	4	4,40%
Education and Training	3	3,30%
Harvard Business Review	3	3,30%
International Journal of Art & Design Education	3	3,30%
Academy of Management Learning & Education	2	2,20%
Comunicar	2	2,20%
International Journal of Technology and Design Education	2	2,20%
Journal of Engineering Design	2	2,20%

Table 2 Educational areas of selected papers

Knowledge area	Number of papers	Percentage of 83
Multidisciplinary	14	16,87%
Management	12	14,46%
Engineering	11	13,25%
Design	10	12,05%
Education	9	10,84%
Architecture	3	3,61%
Medicine	3	3,61%
Journalism	2	2,41%
Primary Education	2	2,41%
Other	17	20,48%

(12.05%). It is a surprising result because Design was the last area in which DT was implemented. Also, it was observed that in recent years, DT has begun to be applied in disciplines such as Political Sciences and Medicine. The explanation for this phenomenon lies in the fact that DT provides a focus on people.

In order to carry out a content analysis of the articles focused on Engineering and Multidisciplinary areas (with the exception of two, the others mix Engineering students with other disciplines), the typology of the selected articles was analyzed by defining three categories:

- Theoretical: They delve into the framework of DT in Education making theoretical contributions or discussing its application (5 out of 24 articles).
- Educational Experiments: They analyze the application of DT in a controlled environment and have students as the subject of study (17 out of 24 articles).
- Real Experiences: They relate the experience of applying DT in a project that involves students and real social agents, for example, NGOs (2 out of 24 articles).

The analysis of the contents showed that the vast majority of papers focused on DT as a tool for developing creativity, critical thinking, and teamwork. The most applied methodology was Brown's [3], although they also applied their own techniques, (though always inspired by the work of Brown [3]. Analyzing the main orientations of this methodology, the reason for its popularity is easily understood; all adapt perfectly to the challenges posed in the teaching of Engineering:

- Integrative Orientation: It presents students with a challenge and encourages them to make use of available technology in order to produce the correct solution. This perspective is the one that most prevails in the multidisciplinary articles which combine Engineering and Management.
- Prototype Orientation: DT is highly experimental and is based on the empiricist process of "idea-prototype-test". This approach is used from the perspective of Design as a way to create, test, and improve products.
- Double Diamond Perspective: Its objective is to encourage creative ideas. It applies divergent thinking to explore many solutions and then uses convergent thinking to reduce their number until a final solution is reached.
- Human Orientation: People are the center of DT, both as end users and in the relationships that are generated during the development of the project (seeking the group's welfare). The need to transmit these values to future engineers is the main idea that underlies the teaching application of DT.

In relation to the objectives and results of the application of the methodology, conclusions from three areas were obtained: Application of the method, Comparison of methods, and Development in specific stages.

Regarding the first, there are experiences such as those focused on evaluating the results of the DT application in its entire dimension for developing soft skills and analyzing the final result of the activity [6, 7, 10, 8]. Studies show positive results from the application of DT. Regarding the second, the experiences focused on comparing DT with other methodologies found that DT was superior to other new teaching and traditional methodologies. For example, Tsai [16] compared the results

of several innovative and classic techniques with DT. His results showed that DT methodology was far superior to other methodologies, especially when exam results were compared. Regarding the third, the last type of application of DT methodology occurs when teachers decided to delve into one of DT's phases (Ideation, Prototyping, or Implantation), as was the case of the studies by Taleyarkhan et al. [13] and Greenhalgh [4]. These papers focused on prototyping and used technologies such as CAD software and 3D printing, respectively. Both experiments showed that it was very useful to rely on these tools in this phase and that they also achieved significantly higher results than without using them. Taura et al. [14] studied the application of DT, and focused on the "ideation" phase in fostering creativity. In the experiment, they presented a problem to students, who were given a short time to define the solution. The results showed that those who knew DT could face the challenge more easily. The authors concluded that thought patterns influence the ideas generated and that DT methodology offered a "recipe" to generate more creative solutions. Behm et al. (2013) and Alhamdani [1] found similar results for this phase.

Finally, the main standard recommendation culled from all the articles was the need to carry out Design Thinking for a more extended period of time. Most of the experiences were short-time workshops. Also, many papers point out the need to introduce it in the curricular training of students as a technique for learning how to face complex problems. The most interesting direction proposed for future research was to go further in the collaboration between society and education by applying DT to help NGOs and disadvantaged groups. Other interesting lines were to delve into the educational technique itself, analyzing how personalities influence multidisciplinary teams' performances, how groups react to different environments (music, work areas, and so on) and address the need to develop an optimal method for evaluating results and the skills acquired.

4 Conclusions

The systematic review of the literature has revealed that Design Thinking is a proper teaching methodology for engineering areas and other disciplines. This technique achieves an increase in student's soft skills and is also a way to obtain innovative solutions. This is because the human orientation of Design Thinking provides at least two benefits. On the one hand, it provides solutions focused on the users' experiences. On the other hand, it provides a good working environment for finding creative solutions. Both aspects are the main goals of any modern profession. Higher Education must transmit this orientation to students at the outset of their learning.

In addition, this paper has demonstrated that the most applied technique of Design Thinking is the one created by Brown [3], because of its simplicity and its flexibility, it has become established as a standard in the field. Therefore, future applications of Design Thinking should follow its indications and introduce the fewest modifications to obtain comparable results.

In conclusion, the analysis of the practical experiences allows concluding that Design Thinking workshops in engineering education enhance creativity, teamwork, and critical thinking more than other innovative teaching methodologies do. Therefore, Design Thinking will grow in the educational sphere and in society, because it has been revealed to be the best technique for facing complex problems which focus on people's needs.

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