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What is the state of the art regarding the application of Design Thinking in Higher Education? A scoping review

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ABSTRACT
Design Thinking (DT) remains a fuzzy concept when applied to education. This prompted the present scoping review (2008-2022), following Arksey and O'Malley's framework. From 2853 Web of Science articles, only 172 met inclusion and exclusion criteria. Results show: (a) There is no agreed definition of DT. (b) There is a variety of tools, techniques and models used to support DT. (c) Most-assessed outcomes of DT are about creativity, teamwork, and problem solving. There were 100 out of 172 studies that included an evaluation of DT interventions. Research instruments were mainly based on student self-reports. Most empirical studies reported a positive impact. (d) Only 12 empirical studies involved control groups, while 37 adopted a pre-test and post-test design. Intervention duration ranged from 90 minutes to one year. The median of the number of participants was around 47. DT presents an interesting research agenda but also there is a need for robust evidence-based intervention studies.

Keywords: design thinking; higher education; scoping review; 21st century skills.

¿Cuál es el estado del arte de la aplicación de *Design Thinking* en la educación superior? Una revisión de alcance de la literatura

RESUMEN
Design Thinking (DT) sigue siendo un concepto difuso, así como sus resultados. Esto motivó la presente revisión de alcance de la literatura (2008-2022), en la cual se aplicó el marco propuesto por Arksey y O'Malley. Usando la plataforma *Web of Science*, se obtuvieron 2853 artículos, de los cuales solo 172 cumplieron con los criterios de inclusión y exclusión. Los resultados muestran que: (a) No existe un acuerdo en la definición de DT. (b) Hay una variedad de herramientas, técnicas y modelos utilizados para aplicar DT. (c) Las habilidades más comunes -asociadas a intervenciones de DT- son creatividad, trabajo en equipo y resolución de problemas. Solo 100 de 172 estudios incluyeron evaluaciones de las intervenciones de DT. Los instrumentos de investigación se basaron principalmente en auto reportes de estudiantes. La mayoría de los estudios empíricos reportaron un impacto positivo. (d) Solo 12 estudios empíricos involucraron grupos de control, mientras que 37 adoptaron un diseño de evaluación pre-prueba con post-prueba. Se encontró que las intervenciones de DT duraron desde 90 minutos hasta un año. La mediana del número de participantes en las intervenciones fue de 47. DT presenta una agenda de investigación interesante, pero también existe la necesidad de más estudios robustos, basados en evidencia.

Palabras clave: design thinking: educación superior; habilidades del siglo XXI; revisión de alcance.

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1. Introduction

University curricula are being challenged to equip students with competences to tackle problems in a changing society. Many universities started adopting programs to pursue the so-called 21st century skills, focusing on – among others – creativity, critical thinking, communication and collaboration (Lemke, 2002; P21, 2007). An educational approach to develop such skills is labelled as Design Thinking (Scheer et al., 2012).

Design Thinking (DT) was first coined in the 1969 book 'The science of the artificial' of Simon (1969). During the last decade it has become a popular concept adopted by companies and key universities. A renowned author in the DT domain defines it as: "a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity." (Brown, 2008, p. 2)

The rise of DT is reflected in the literature study of Spee and Basaiawmoit (2016), who concluded DT was virtually non-existent in research prior to 2008. Since then, the increase in DT-attention has not stopped. Universities consider DT as a way to expose students to skills and knowledge beyond their own disciplines through multidisciplinary teamwork (Wrigley & Straker, 2015).

Since 2008 there has been a rise in literature reviews about DT in higher education (e.g., Fleury et al., 2016; Johansson-Sköldberg et al., 2013; Matthews & Wrigley, 2017). There are different approaches regarding DT application. The most common uses are as a means for developing 21st century students' skills and mindsets (Wright & Wrigley, 2019), for increasing learning motivation (e.g., Hsu et al., 2021), as a way to improve the curriculum from the perspective of designers (e.g., Crites & Rye, 2020), or for innovating educational systems (Tschimmel & Santos, 2019). Besides, there are also studies addressing design thinking from the perspective of design as a profession (e.g., Gero & Milovanovic, 2020). However, despite of the apparent abundance of available studies pointing at the development of skills as a result of a DT intervention, most of them barely address the impact on students' outcomes comprehensively, which is decisive to support the implementation of DT in universities.

Therefore, the purpose of this paper aims to develop a state-of-the-art picture about DT focused on its outcomes in higher education. The review aims at answering four research questions: (Q1) What are the characteristics and dimensions of DT?; (Q2) What are the ways to develop DT in Higher Education?; (Q3) What have been the outcomes of the DT interventions in Higher Education and which assessment instruments have been used?; (Q4) What research design has been used in empirical studies that assess a DT intervention in Higher Education?

The scoping review in this article builds on the literature since 2008 as indexed on the Web of Science. The review follows Arksey and O'Malley's five-stage framework (2005) to guide the steps taken to map and analyse the literature. In addition, we enriched our article selection process with the Preferred Reporting of Items for Systematic Reviews and Meta-Analyses Approach (PRISMA) of Moher et al. (2009).

2. Methods

The five-stage framework of Arksey and O'Malley (2005) follows five steps: (i) identifying the initial research questions, (ii) identifying relevant studies, (iii) study selection, (iv) charting the data, and (v) collating, summarizing and reporting the results.

2.1 Identification of the research questions

With universities' increasing interest in DT, we are keen on exploring the key aspects of DT in higher education, specifically the impact of a DT intervention on students. We defined a broad range of research questions:

(Q1) What are the characteristics and dimensions of DT?

(*Q2)* What are the ways to develop DT in Higher Education?

(Q3) What have been the outcomes of the DT interventions in Higher Education and which assessment instruments have been used?

(*Q4)* What research design has been used in empirical studies that assess a DT intervention in Higher Education?

2.2 Identification of relevant studies

The Web of Science (WOS) was used to identify English language peer-reviewed articles and conference proceedings, with the following search terms: 'Design Thinking' as a topic; OR 'Design Thinking' as a title. WOS was selected since it is a renowned academic research database that offers a curated collection of peer-reviewed, high-quality scholarly journals published worldwide in science, social sciences, and humanities disciplines, as well as conference proceedings. The time window from 2008 till June 10th, 2022, was applied. The year 2008 seems to be the starting year in which DT literature got published. Table 1 lists the inclusion and exclusion criteria to track literature, building on the key concepts in the research questions.

2.3 Studies selection

Figure 1 depicts the article selection process following the PRISMA approach (Moher et al., 2009). Application of the search criteria resulted in an initial set of 2853 articles. All individual articles were reviewed building on the inclusion and exclusion criteria. Only 172 studies met the inclusion criteria.

The large number of excluded studies (n=2681) can be explained by looking at the nature of the publications. As reflected in Figure 2, 2169 studies had to be excluded on the base of the criterion 1 or 3. Most excluded articles focused on Design as a profession/practice, or analysed DT as a study field, or studies were not set up in - hardly specified - higher education settings.

2.4 Charting the data

At this stage all selected articles were screened to extract data to answer the research questions. The resulting table is added as supplementary material to this paper, in the following link: https://biblio.ugent.be/publication/8769341

2.5 Collating, summarizing, and reporting the results

The final stage of Arksey and O'Malley's framework (2005) focuses on synthesizing the analytical findings as outlined in the next section of this article.

3. Results and Discussion

From the 172 studies, 100 studies reported in addition on an empirical study to assess outcomes of a DT intervention. For the convenience of readers, from now on, we will use numbers in italics as references to the corresponding studies involved in each research question. Those numbers match the column 'Study number' included in the supplementary material.

Table 1.
Inclusion and exclusion criteria. Own elaboration.

Criterion	Inclusion Criteria	Exclusion criteria	Code for each criterion
Topics addressed	Literature review of DT and/or new definitions proposal.	Topics on design as a profession/ practice, or specifically aimed as a field of study (engineering design, design education). Summaries of presentations/ideas in conferences or similar. Other studies where DT is not a core topic.	1
Empirical study	DT as part of curriculum for an undergraduate or graduate program showing any type of empirical result; specially effects of DT outcomes, such as: skills, mindsets, abilities or similar.	Mere experiences or proposals for implementing a DT course without measurement of any empirical result on students. Diagnosis of DT-related skills without a specific DT intervention. Studies using DT in higher education context but not as part of curriculum.	2
Settings and population of interest	Higher education: Undergraduate and Graduate students.	Studies -using DT- carried out at other settings different from higher education (e.g., working environment, business, elementary school, middle school, high school, etc.) or no specification about the educational level.	3
Type of analysis	Methods or tools that affect the DT process, or its uses, as long as these are relevant for student's outcomes: skills, capacities, abilities; as well as tests to measure DT students' outcomes.	New or combined DT methods or its application where the effects of DT on students' outcomes could be blurred or not mentioned.	4
		Evaluation of tools, tests, or stimuli on DT where impact on students' outcomes, such as skills, capacities, abilities, are not addressed. (e.g., ICTs)	5
Other	N/A	Not available, repeated studies, incomplete document or not possible to buy it separately.	6

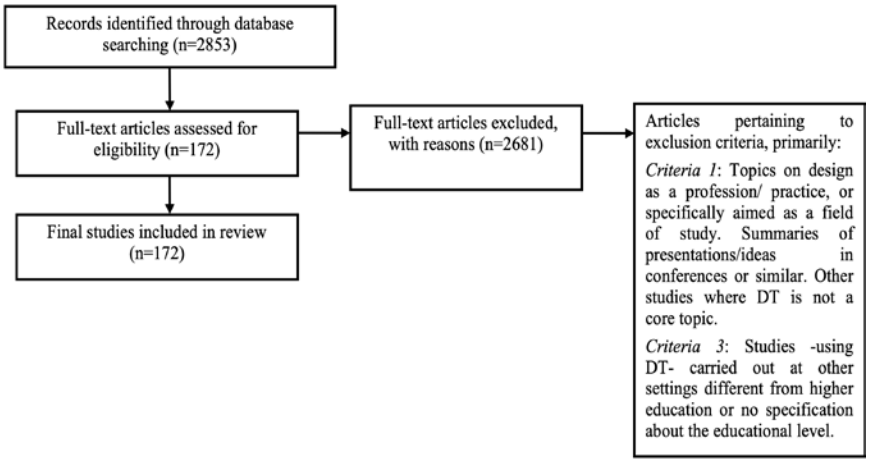

Figure 1. *PRISMA flow diagram for article selection. Own elaboration.*

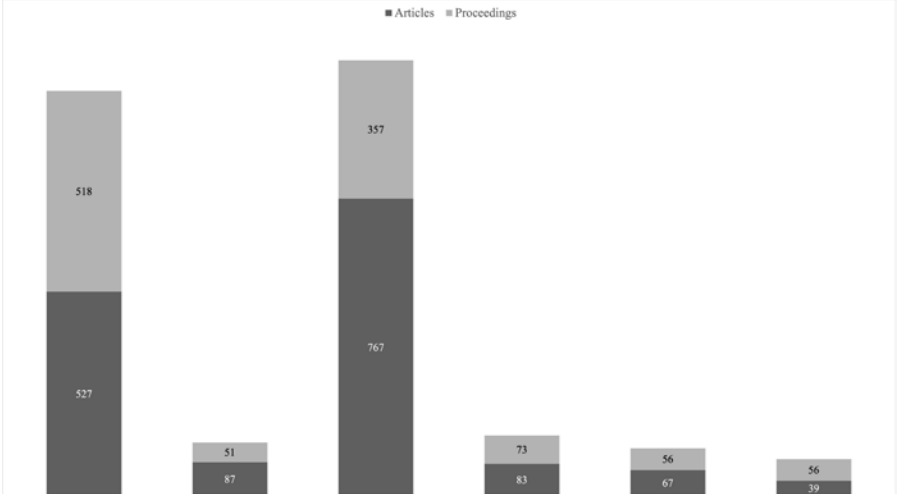

Figure 2. *Number of studies excluded following the exclusion criteria. Own elaboration*

3.1 Q1 = What are the characteristics and dimensions of Design Thinking?

Authors keep repeating there is no clear definition of DT (*26, 43, 49, 52*). We tracked keywords proposed by different authors to develop a definition that incorporates the shared elements of how DT has been conceived through all these years. First, most articles share the definition of Brown (*28*) who defines DT as a discipline that brings together users' needs (desirability), technological feasibility and economic viability.

Other articles stress keywords, such as: a style of thinking (*80*), a problem solving method or methodology (*82, 113, 133, 153*), a hypothesis-driven process and a practice (*58*), a way of thinking and being (*65*), a new paradigm (*37, 112*), a set of contingent, application of design methods by multidisciplinary teams to a broad range of innovation challenges (*67*), cognitive processes and practices designers have in common (*42, 86*), a cross-disciplinary and user centred method (*8*), a team-based innovation method (*56*), a human-centred approach (*137, 149*) applied to 'wicked' problem solving (*40*), the ability to combine empathy, creativity and rationality (*77*), an evolving theoretical practice established outside the traditional design discipline discourse (*61*), a systematic, intelligent process that designers employ to generate and evaluate concepts for devices, systems, or processes (*62*), an interpretation according to the concept of design, both as the creation of material/non-material values, and strategic and systemic approach (*123*) in problem solving (*47*), a way of finding or developing the problems or latent needs using the tools that designers used to use (*48*), a simplification of complex design methods (*94*), a step-by-step (*98*) or a multi-step (*106*) recursive process for complex problems.

From an educational perspective, there are studies referring to DT as a practice-oriented constructivist approach to learning (*84*), a teaching-learning approach that enhance students' creativity (*101*), a framework for 21st century educational innovation (*162*), a new learning environment that would enable students to develop skills (*114*), a learning methodology for solving problems in a non-linear and iterative way (*171*). DT is also seen as a guide for learners to understand and deconstruct problems in a different way compared to the linear and convergent dominant pedagogy (*146*).

In one literature review (*89*) researchers found that DT is seen as a mindset, practice, process, method, methodology, tool, heuristic, and more, which also is confirmed by other works (*97, 130*).

Additionally, it was identified two recurrent DT dimensions in the literature (*30, 49*). One dimension refers to the design practice used beyond the design context, by focusing on definitions provided by renowned advocates and that can be applied by people without a formal background in design. In other words, it is seen as a simplified version of formal design that can be incorporated in other academic and practical fields. On the other hand, the other dimension found in the literature is rooted in the academic design theory and designers' professional practice (their way of thinking and working). The two dimensions seem to crisscross in the literature. The latter stresses design theory or the design professional practice; the other is mostly used beyond design context.

Building on the above, the following definition for DT (an adapted version from Guaman-Quintanilla et al., 2018) is presented: Design thinking is a way of working and thinking that goes beyond the realm of pure design. It is used to solve complex problems by using the methods and mindsets that are usually associated with designers but adapting them to different contexts. It uses a human-centred and prototype-driven approach and aims to promote 21st century skills.

3.2 Q2 = What are the ways to develop Design Thinking in Higher Education?

This review helped identifying DT approaches, tools, and models used to support DT interventions in Higher Education. Additionally, we summarize below key examples that help operationalizing ways to pursue the DT objectives.

3.2.1 DT approaches/stages

We found that there are multiple approaches/stages applied in DT interventions in Higher Education contexts. Nevertheless, we identified three approaches that are the most common or used as baseline for subsequent versions. One of them is provided by Brown (2008) -IDEO- which consists of three stages: Inspiration, Ideation, Implementation. Another one is the presented by Plattner et al. (2009) composed by six stages: Understand, Observe, Point of View, Ideate, Prototype, Test. Finally, the British Design Council (2007) presents a double diamond model that includes the stages: Discover, Define, Develop, Deliver.

3.2.2 Tangible tools analysed in DT settings

There is a myriad of tools used in each stage of DT (d.school at Stanford, 2018; Lewrick et al., 2020) and are commonly mentioned in DT intervention studies. A first tangible tool is physical models (*75*), which vary from rough mock-ups to detailed high resolution prototypes. The authors of study *75* investigated the role of physical models in the idea generation process and how they impact the quality of designs being produced. Secondly, sketching tools (*34*), specifically hand-sketch, tablet, and pen-input display, were used on design studies suggesting a linkage between sketching behaviour and DT. Though no differential impact was found on visual thinking strategies that could be related to the type of tool used in study *34*, their authors concluded that visual thinking – related to DT - is strongly influenced by sketching tools. Study *132* presents the empathy-oriented prototyping toolkit, which combines simple geometric three-dimensional objects made of rubber, wood, metal, acrylic, and marble to elicit tactile feelings. This toolkit replaces paper-based prototype, and it allowed students to develop empathy and express their ideas effectively. Another study (*70*) shows that using a *Persona* – a 'hypothetical archetype of real users' (Pruitt & Adlin, 2006) - improved creative idea generation. In study *23,* researchers explored the role of an empathic design technique on solving design problems. Their qualitative findings illustrated how students developed more meaningful and feasible designs. These researchers reported text-based testimonies, observation through videos or photographs, empathy maps, interviews and focus groups, and immersive practices, as examples of students' use of empathy. The author of study *55* suggests a relationship between using non-hierarchical mind mapping and designers' ability to develop creative and reasoned product designs. In other study (*141*), students were guided through a step-by-step DT approach while using a tool called a Multi-attribute Decision Matrix (MADM) at different stages to determine the best idea toward a more comprehensive solution.

In study *81* a game was applied to facilitate the use of DT by providing an iterative passage through all stages of DT. Researchers in study *122* engaged teachers in a game design

course, which incorporated DT to promote their technical competences, obtaining positive results. In study *124*, researchers posit that game design and DT provide students opportunities for experimentation and innovation. The results summarized in that article show that their intervention (applying a playful approach to DT that is motivated by the game design process, which entails finding solutions to real-world issues) improved students' skills and learning experience. Other studies such as *116* emphasized the use of Lego® Serious Play (Nerantzi & James, 2019) during a DT intervention as a significant tool for encouraging students' creativity, self-expression, and idea generation at the conceptual stage of architectural design. Similarly, in study *159*, researchers asked students to construct physical analogical representations of their view of the problem(s) with the help of Lego construction toys. In this way, students were given the opportunity to visualize their mental images.

3.2.3 Mental tools or techniques analysed in DT settings

This cluster groups tools and builds on boosting specific cognitive processing strategies.

First, analogies and metaphors are commonly voiced as key tools to enhance creative design. They are also labelled as 'reasoning methods' (*32, 33, 45*), in which a situation in one domain is compared with another (*45*). Authors state that analogical and metaphorical reasoning demonstrates to students the diversity in problem solving approaches; thus, leading to a more creative design process (*33*).

The second tool - reflection - was addressed by several authors. Study *73* explains how reflection leads to knowledge construction through recursive interpretations of one's personal experiences or beliefs that contribute to design judgments, decisions, and actions. In study *102*, students used reflection-on-action to record and evaluate how students' sustainability projects included the DT process. DT relies on coupling formal methods (need finding, brainstorming, prototyping) with reflexive team practices (*67*). Reflective thinking helps designers gain knowledge and synthesize ideas. Students' ability to work using DT and push limits through questioning and probing demonstrates reflective thinking to transform perception into knowledge (*94*).

As a third tool, in study *5*, authors present the use of a Logbook, where students are asked to reflect on their logbook entries. The logbook was used as part of a metaphor about design projects being a kind of backpack trip, or exploratory journey. The reflective logbook use resulted in stronger creative performance. In study *80*, researchers used blogging as an instructional approach for supporting DT education. The tool enabled active DT knowledge building and personal reflection on design practices. However, it hampered the engagement of students who were less comfortable sharing their ideas on open networks.

Another mental tool is abstraction (study *78),* which pushes users to reduce the number of categories of data to be processed by creating a concept and seizing the core information. The researchers concluded that abstraction helps connecting new information to available information. Also, study *51* focused on the development of abstract reasoning. In that study, abstraction was defined as the process by which concepts are derived from actual usage, typically through reduction of the information content to retain only relevant information for a particular purpose in the context of a design.

The last tool in this cluster is taken from study *25* about problem framing: the *Storytelling metaphor*. Those authors argue that a design team must first understand the story of how things are today to be able to create a new story to be materialized and rolled out for the future.

3.2.4 Web-based tool for teaching DT

In study *63*, an online tool named Divergent & Convergent Thinking (DCT) was introduced to help students develop skills associated with divergent and convergent thinking. DCT assisted students to solve a problem via two phases. The first phase consisted of understanding, analysing, and restating the problem. The second phase brought students to the problem-solving process by guiding them in the generation of multiple ideas and in helping to choose the best one.

As a result of the pandemic, the use of web-based tools was intensified in DT interventions. In study *97*, students used a digital whiteboard, which helped with visualization and idea sharing but impeded using pens and sticky notes, together. In fact, those researchers suggest that using current technology to enable students to develop DT skills and engage with real-world situations (outside of their classes) is more important than investing in the technical improvement of DT tools. Even before pandemic, WebQuests and Vialogues (online videos to foster dialogue) were already being used in conjunction with DT (*84*).

3.2.5 Models, frameworks and tools proposed to support DT interventions

A first model, 'The Educational Design Ladder' (EDT), was found in study *77*. It was developed to support the teaching and assessment of DT. It supports the process of organizing and structuring of units in a multidisciplinary DT program. The five-step model guides stages in DT development and guarantees the development of knowledge and skills that are applicable to DT. These authors stressed some guiding instructional design principles for teaching and learning in DT courses, such as (a) knowledge is acquired through practice, rather than traditional learning; (b) the need of setting up cross-disciplinary project work to develop and share skillsets; (c) the importance of working on real-world problems, for real clients and real responsibility; and (d) the willingness to take risks and to try new things. All these should also be at the core of DT assessment.

A second model, (study *57)*, 'Ambidextrous Mindsets for Innovation', is used for engineering students to navigate design and engineering activities. It is a matrix showing the relative positions of DT (as the practice of conceiving and solving a problem, with the ultimate result being an idea), Engineering Thinking (making a solution that leads to an artifact that offers an answer to a defined problem), Production Thinking (remaking of a solution that ends up making copies), and Future Thinking (reframing a problem with the outcome becoming a question). The implications suggested educational benefits for students to navigate between design and engineering activities, which are both needed to foster innovation.

A third finding is the 'D-Think Toolkit', presented in study *105* as a framework with the purpose of understanding and encouraging the use of DT in an educational system's innovation process. It is intended to be utilized by teams composed of educators, other educational stakeholders, and students.

There are other proposals such as in study *144* that presents the design and evaluation of a course that combines DT with the 'Moonshot' framework (efforts to make big breakthroughs in solving complex problems). According to the authors, the goal was to fill in some educational gaps in both approaches which have similar learning outcomes. In the literature other frame-

works that include DT have emerged. For instance, the 'Entrepreneurial Dynamic Learning' (*145*), which integrates the principles of entrepreneurship education, active learning, DT, and Bloom's Taxonomy developed to foster engineering students' entrepreneurial skills. Other study (*148*) introduces the 'Generative Dialogue Framework' as a pedagogical intervention to reimagine the future of engaged journalism by integrating DT practices, creativity, and deep listening. It uses virtual meeting technology to set up small-group conversations, lets people share stories through creative activities, and promotes mutual understanding and co-creative problem solving. The last framework is the 'Design-led Education Innovation Matrix' (*162*), a prototype framework to help educators develop and assess 21st century knowledge, skills, and mindsets. This framework gives students a way to improve their skills in both formal and informal settings at every step of design-led education.

The tools and models to develop DT seem to fit the definition and characteristics of DT as presented in the results of the first research question. It emerges that neither the tools nor the models are standardized in view of typical DT phases, and it is still up to each individual person how to apply or teach DT. Other researchers (*40*) stress the lack of standardization in relation to DT phases, tools, and practices (*113*). In study *64*, authors recommend therefore to conduct studies to understand the nature of DT, the way it can be taught/applied in different settings, and what are its outcomes. The actual reasons why and how the tools or models are expected to play a role are not yet well grounded in the literature. Hence, researchers stress that DT needs a stronger foundation in a comprehensive body of knowledge (*49*). Therefore, it is evident that DT remains undertheorized (*52, 103*).

3.3 Q3 = What have been the outcomes of the Design Thinking interventions in Higher Education and which assessment instruments have been used?

In view of adopting DT in universities, it is important to know what outcomes are pursued via DT; especially empirical outcomes for grasping the potential of future DT interventions. Next, it is important to know the research instruments used in those studies, as well as the type of impact reported by those interventions. In Table 2, we present a summary of (a) the reported outcomes, (b) the instruments used for assessing those outcomes, and (c) the type of impact obtained (positive, negative or no impact).

Table 2.
Studies that assess a DT intervention: assessed outcomes, instruments used, and reported type of impact. N=100. Own elaboration

Outcomes assessed in empirical studies	N	Instruments used in the empirical studies								Type of impact reported in the empirical studies		
		Surveys/ Questionnaires	Interviews, focus groups, discussions	Reflection pieces, including journals	Tests and performance deliverables	Observation	Rubric to assess skills	Not specified	Other	Positive Impact	Negative Impact	No Impact or not clearly defined
		N=66	N=31	N=23	N=17	N=13	N=3	N=3	N=4	N=92	N=2	N=8
Creativity	43	3, 10, 80, 81, 84, 91, 94, 96, 102, 107, 108, 114, 116, 117, 118, 120, 121, 124, 125, 127, 138, 143, 147, 153, 154, 155, 163, 165, 167, 172	80, 83, 93, 97, 102, 117, 120, 121, 126, 128, 138, 153, 161, 172	80, 91, 94, 101, 102, 108, 150, 153, 159	5, 19, 124, 150, 159, 167	83, 117, 126, 159	129		13, 153, 159	3, 5, 13, 19, 80, 81, 83, 91, 93, 94, 96, 97, 101, 102, 107, 108, 114, 116, 117, 118, 120, 121, 124, 125, 126, 127, 128, 129, 138, 143, 147, 150, 153, 154, 159, 161, 163, 165, 167, 172	155	10, 84
Teamwork and collaboration	41	3, 6, 10, 16, 18, 80, 84, 90, 91, 94, 108, 110, 113, 116, 118, 120, 121, 124, 127, 134, 135, 136, 143, 144, 153, 158, 160, 167, 171	16, 80, 90, 97, 120, 121, 128, 134, 135, 153, 158, 171	3, 8, 11, 80, 91, 94, 101, 108, 115, 135, 150, 153, 164, 169	12, 124, 135, 150, 167	8, 90, 135, 171	100	151	153	3, 8, 11, 12, 18, 80, 84, 91, 94, 100, 101, 108, 110, 113, 115, 116, 118, 120, 121, 124, 127, 128, 134, 135, 136, 143, 144, 150, 151, 153, 160, 164, 167, 169, 171	6	10, 16, 90, 97, 158
Problem solving	36	4, 7, 9, 17, 80, 81, 91, 94, 96, 107, 110, 116, 117, 118, 119, 120, 121, 124, 139, 141, 155, 158, 167, 171	2, 17, 80, 83, 110, 117, 120, 121, 123, 158, 171	2, 8, 17, 80, 91, 94, 159, 164, 169	1, 12, 119, 123, 124, 139, 159, 167	4, 8, 83, 117, 123, 159, 171	129	149, 151	159	1, 2, 4, 7, 8, 9, 12, 17, 80, 81, 83, 91, 94, 96, 107, 110, 116, 117, 118, 119, 120, 121, 123, 124, 129, 139, 141, 149, 151, 158, 159, 164, 167, 169, 171	155	

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		N=66	N=31	N=23	N=17	N=13	N=3	N=3	N=4	N=92	N=2	N=8
Human-Centred awareness and Empathy	27	3, 14, 16, 18, 90, 91,110, 118, 120, 124, 138, 139, 143, 153	15, 16, 90, 97, 110, 120, 132, 138, 148, 153, 168	3, 11, 14, 91, 101, 106, 115, 140, 148, 153, 159, 169	85, 124, 139, 140, 159	90, 132, 140, 159			153, 159	3, 11, 14, 15, 18, 85, 90, 91, 97, 101, 106, 110, 115, 118, 120, 124, 132, 138, 139, 140, 143, 148, 153, 159, 168, 169		16
Attitudes and values	26	3, 16, 90, 91, 99, 110 107, 111, 113, 118, 121, 134, 136, 143, 144, 153, 154, 157, 163, 165, 166	83, 91, 111, 121, 128, 134, 153	3, 153, 169		83, 111		149, 151	111, 153	3, 83, 90, 91, 99, 107, 111, 113, 118, 121, 128, 134, 136, 143, 144, 149, 151, 153, 154, 157, 163, 165, 166, 169		16, 110
Higher Order thinking	25	3, 16, 88, 91, 96, 110, 118, 120, 121, 135, 141, 143, 152, 155, 163, 167, 171	16, 110, 120, 121, 135, 161, 171	3, 91, 101, 106, 115, 135, 164, 169	5, 135, 167	135, 171		151		3, 88, 91, 96, 101, 106, 115, 118, 120, 121, 135, 141, 143, 151, 152, 155, 161, 163, 164, 167, 169, 171		5, 16, 110
Communication and networking	22	7, 9, 17, 91, 107, 108, 113, 116, 117, 134, 135, 152, 153, 154, 167	17, 83, 117, 132, 134, 135, 153, 168	17, 91, 108, 115, 135, 153, 164, 169	135, 167	83, 117, 132, 135		87	153	7, 9, 17, 83, 87, 91, 107, 108, 113, 115, 116, 117, 132, 134, 135, 152, 153, 154, 164, 167, 168, 169		
Learning experience/ motivation	21	16, 81, 88, 91, 96, 114, 116, 117, 119, 120, 121, 138, 143, 144, 156, 166, 170, 172	15, 117, 120, 121, 123, 138, 172	91, 169	119, 123, 170	117, 123				15, 81, 88, 91, 96, 114, 116, 117, 119, 120, 121, 123, 138, 143, 144, 156, 166, 169, 170, 172		16
Field-specific outcomes	17	92, 102, 122, 127, 133, 134, 136, 163, 165, 167, 171	102, 122, 134, 161, 168, 171	102, 131, 140	109, 122, 140, 167	140, 171	131	87		87, 92, 102, 109, 122, 127, 131, 133, 134, 136, 140, 161, 163, 165, 167, 168, 171		
Entrepreneurial mindset and innovation self-efficacy	11	19, 20, 95, 96, 145, 160, 171	15, 161, 171	150, 164	150	171				15, 19, 20, 95, 96, 145, 150, 160, 161, 164, 171		
Experimenta-tion and proto-typing	9	3, 14, 16, 121, 143, 152, 171	16, 121, 171	3, 14, 150	12, 150	171				3, 12, 14, 121, 143, 150, 152, 171		16
Other	16	14, 16, 84, 108, 113,121, 136, 147, 152, 166, 171	121, 161, 171	14, 106, 108, 131, 169	12	171	131			12, 14, 84 106, 108, 113, 121, 131, 136, 147, 152, 161, 166, 169, 171		16

Note: The numbers shown are linked to the column 'Study number' of supplementary material.

3.3.1 Reported outcomes after a DT intervention

From the 100 empirical studies obtained, there were a myriad of outcomes reported after a DT intervention. The detail of each of those outcomes can be found in the supplementary material. For an easier presentation, Table 2 brings together the concrete outcomes into broader groups. The latter results in 12 groups, as follows: Creativity (n=43), Teamwork and collaboration (n=41), Problem solving (n=36), Human-Centred awareness and Empathy (n=27), Attitudes and values (n=26), Higher order thinking (n=25), Communication and networking (n=22), Learning experience/motivation (n=21), Field-specific outcomes (n=17), Entrepreneurial mindset and innovation self-efficacy (n=11), Experimentation and prototyping (n=9), Other (n=16). It can be observed a stronger emphasis on 'skills'. Moreover, it is interesting to observe that the outcomes, aimed at in the DT literature, are strongly related to the 21st Century Skills (Lemke, 2002).

3.3.2 Tools used for assessing DT results

As shown in Table 2, most of the empirical studies built on surveys/questionnaires (n=66), followed by interviews, or focus groups (n=31), reflection pieces (n=23), tests and performance deliverables (n=17), observation (n=13), rubrics to assess skills (n=3), other (n=4) and 3 studies did not specify which instrument was used to collect data. Most of the instruments mainly help collecting qualitative data based on self-reports. Authors often adopt pre-existing instruments (e.g., *5, 10, 19, 100, 129, 131*).

We can conclude that in most cases DT measurement does not build on a standardized set of research instruments or protocols. Most authors use what they consider being appropriate or available. This suggests a need to develop and apply more stringent, validated, and reliable instruments.

3.3.3 The results of empirical studies that assess a DT intervention in Higher Education.

Table 2 shows that most evaluative studies of a DT intervention report positive results in at least one outcome: 92 out of 100. Only two studies report negative outcomes; eight studies found outcomes with no impact, or the impact was not clearly defined. Moreover, there is one study (*155*) that reports positive results for one outcome (the ability to think in both divergent and convergent ways) and negative results for creativity and problem solving. The details of those studies can be found in the supplementary material.

As presented in Table 2, creativity, teamwork and problem solving are, by far, the most assessed outcomes. These outcomes reported a negative effect once (see *6, 155*). Nevertheless, the studies reporting positive results in those three outcomes outnumber the negative reports, by far. There is one study (*155*) that presented positive results for higher order thinking skills and negative results for creativity and problem solving. These ambivalent results invite a closer look at the nature of the actual evaluation studies. Study *155* combined DT with the conceive, develop, implement, and operate (CDIO) engineering design framework. Using questionnaires, it was found that the DT-CDIO was negatively correlated with creativity and problem solving. The authors suggest that psychological emotions, insufficient time to learn the DT-CDIO framework, among other, may affect the results. On the bright side, most of the 45 students learned to think divergently and convergently.

There are also other studies that show ambivalent results since they reported both positive impact and no impact (or not clearly defined): *5, 84, 90, 97, 110, 158*.

Interestingly, there were three studies that did not report any positive result on any outcome (*6 10, 16*). Below we explain what happened in this last group of interventions. First, in study *6*, authors were disappointed to realize that, while some students found the activities highly beneficial, most saw them simply as 'busy work' with low appreciation of teamwork opportunities. On the other hand, teaching staff was frustrated by the online reflective tools and recognized that the actual DT implementation was flawed, e.g., the program syllabus did not provide enough guidance for teamwork; the curriculum was crowded, and assessment delivery was inappropriate. The authors concluded that the key problem is a matter of balance. Apparently, too many exercises related to teamwork undermined its usefulness and faculty were less involved in teamwork pedagogy due to automation when administering the activities. The next intervention that did not report any positive impact is the one reported in study *10*. The research results showed no impact on students' creative self-efficacy; their attitudes towards teamwork remained stable. Authors explained these results by looking at the group format that might have hindered the development of creative self-efficacy. They also suggested that the course content and delivery might have reflected an insufficient focus on creativity, a too low emphasis on teamwork, and did not give students sufficient time for working out ideas. The third intervention in this group is study *16*, where 20 Korean students reflected low scores for outcomes related to teamwork, experimentation, human-centred awareness, higher order thinking and other. According to the authors, these results can be partly explained by looking at the Korean culture. The survey results also seemed inconsistent with interview data that point at students reporting that the course helped cultivating creativity.

The above research results mirror the variety of aims being pursued in a DT context, although the focus seems mainly on creativity, teamwork and problem solving. Despite the predominant positive results, these must be approached carefully, given the – sometimes weaker - research design characteristics of the studies as exemplified above. Also, many studies have reported applying DT with another methodology or tool (see results of RQ2), or even with active-learning strategies such as flipped classroom, project-based learning, etc. (e.g., *110, 138, 170*), where it is hard to define to what extent the results are influenced by DT.

3.4 Q4 = What research design has been used in empirical studies that assess a DT intervention in Higher Education?

Building on the 100 empirical studies, we identified shared research design elements. Only twelve out of 100 studies included control groups (*1, 5, 13, 14, 20, 102, 108, 118, 121, 126, 138, 150*). Likewise, only 37 out of 100 studies applied a pre-test - post-test design (*5, 7, 10, 13, 14, 19, 20, 80, 92, 100, 102, 106, 107, 110, 115, 119, 120, 122, 125, 127, 129, 131, 133, 138, 141, 143, 144, 151, 152, 153, 157, 160, 164, 165, 166, 170, 172*). In most studies – 63 out of 100 studies – outcomes were only measured once, or this information was not specified; thus, falling short in being able to assign changes or differences to the actual DT intervention.

The duration of the DT interventions ranges from 90 minutes to a year; for details see the supplementary material. The median of participants in DT studies is around 47, with a wide range that goes from four participants (*171*) to 910 (*129*).

The above observations reflect a weak research design since most of the studies are less able to demonstrate whether changes in DT outcomes can be linked to the actual DT intervention. Lack of a control group affects a generalization of the findings. The same can be said about the small sample sizes that jeopardize being able to attain statistically significant and reliable results.

The lack of a systematic assessment of DT benefits (*58*) is aggravated by the lack of accurate, performance-based measures of DT (*65*). It is urgent the development of comprehensive DT assessment approaches that fit the complex nature of DT (*15*). Nevertheless, authors of study *29* state that various studies seem adopting a more formal, factor controlled, and hypothesis testing driven approach, which helps the application of more rigorous statistical analysis techniques.

Finally, in a recent literature review on DT (*112*), researchers claim that insufficient attention has been paid to mixed approaches for investigating the determinants and outcomes of DT, which is confirmed by the present review, since only 19 studies -out of 100- reported a mixed-method approach. The majority of empirical studies apply one approach only; the most common is qualitative.

4. General Discussion and Conclusions

In Higher Education, DT is often embraced as an innovation to pursue the so-called 21st century skills. DT is being adopted by a growing number of universities. The present scoping review about the adoption of DT focused on four key questions to track the nature of DT implementations in Higher Education. We attempted to characterize DT and to develop a working definition. Projected outcomes of DT did vary to a large extent. The empirical studies show that creativity, teamwork, and problem solving are the most assessed outcomes.

Given the large variety of DT outcomes, it was not surprising that also a variety in tools and models were found to implement DT in an operational way.

When looking at evidence-based DT research, it is striking to see that only a minority of studies have a rigorous enough design to allow generalization and drawing conclusions about the studies' actual impact. This was also reflected in the research instruments that mainly build on self-reporting data. In addition, few studies adopted mixed methods. The vast majority of the empirical studies seem reporting positive results, but this observation is marred by the nature of the research designs and research instruments. We observe very few studies adopting other actor perspectives (e.g., *100, 129*) while assessing the impact of a DT intervention. Next to students, more attention should be paid to teachers, solution users, real-problem owners, etc. Additionally, most results were collected individually from students, this conflicts with the collaborative nature of most DT activities.

Some challenges when implementing DT have been put forward by several researchers. For example, in study *5*, authors point at course delivery flaws. Since there is no standardized way to set up DT interventions, the results obtained seem susceptible to course delivery characteristics. The integration of DT into already-busy curricula presents another challenge (*139*). Time is a current problem reported by several researchers (*84, 94, 97, 134, 158, 160)* since students and teachers claim the need for more time to go through the DT process and appreciate its impact fully. In this regard, students seem to become impatient and want to achieve quick results. Also, getting teams to work effectively requires time, as suggested in studies *94* and *158.* Despite the shortcomings related to DT interventions and DT research, DT is a promising agenda for curriculum design, as also stated elsewhere (*98, 112, 133*). However, researchers will have to tackle an uphill road to be able to assess, in a robust way, the effects of DT interventions.

The present scoping review reflects some weaknesses. Because of the strict focus on WOS-indexed publications from 2008 to June 2022, we might have missed literature published in alternative publication outlets. Also, the focus on English language literature could have introduced a bias towards a specific strand of research. Lastly, the literature analysis mainly focused on the nature of DT and the empirical studies. Future studies could centre on the theoretical underpinning of DT to explain and describe expected outcomes and help qualifying the instructional design of DT interventions. This appears to be a critical step forward in preventing DT from becoming just a passing trend in Higher Education.

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