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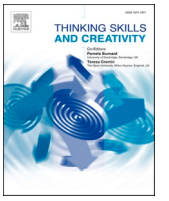

Making design thinking for education sustainable: Training preservice teachers to address practice challenges

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ABSTRACT

The effectiveness of design thinking (DT) education is increasingly demonstrated; it allows teachers to face complex challenges in their day-to-day work. However, few teachers have training in this discipline. This study presents the 'Think-Create-Teach' (TCT) methodology to help preservice teachers to create instructional materials guided by DT. The TCT methodology is applied and assessed through quantitative methods in a project-based learning subject with 56 preservice teachers (experimental group). Subsequently, the work processes and instructional materials developed by the experimental group were compared to a control group of 52 preservice teachers who did not use TCT. The quantitative results were supported with qualitative methods to understand the reasoning behind. This paper demonstrates the TCT contribution to designing better instructional materials, its integration into the teaching curriculum, its validity as design training, and its ability to help teachers answer today's changing education. This paper shows that design discipline and the methodology proposed have a relevant role in the training of preservice teachers.

1. Introduction

Society constantly evolves and generates significant challenges and consequences in all areas of society (Gisbert & Esteve, 2016), including education (Luka, 2014; Sancho-Gil & Hernández-Hernández, 2018). Jobs increasingly require teams with boundary-crossing skills, which requires training future professionals differently (Achtenhagen, 2001; Blanco et al., 2017a; Bullen & Morgan, 2016; Carroll et al., 2010; Daly et al., 2012; Gallardo-Echenique et al., 2015; Jenkins et al., 2009; Tulsi & Poonia, 2015). Consequently, the traditional educational methodology, mainly based on teacher instruction, passive learning through copying, memory, or reproduction (Lee & Erdogan, 2007; McMullan, 2016; Nguyen et al., 2017; Qi, 2017; Zhang & Guo, 2017; Zhao & Meng, 2015), and evaluation through standardised tests (Carroll et al., 2010), is frequently ineffective to satisfy the new educational and social needs (Luka, 2014). Thus, in recent years, the competency-based educational approach has modified the traditional methodology (Blanco et al., 2017b;

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Hoogveld et al., 2005; Martínez et al., 2019). This approach includes training students in communication, teamwork, critical thinking, and creativity (Carroll et al., 2010; Razzouk & Shute, 2012). However, these skills are often difficult to convey to students (Wilhelm et al., 2002).

In this context that Jordan (2016) defines as 'shifting educational trajectories', the teacher role is crucial. The teacher's work does not only imply transmitting knowledge to students but must also support skill development. Teachers must adopt new roles as coach, resource provider, and designer (Hoogveld et al., 2005; López, 2008; McKenney et al., 2015; Razzouk & Shute, 2012). In practice, teachers face complex and varied challenges: they design their classes, instructional materials, lesson plans, or teaching methodologies. Likewise, teachers must adapt themselves to the needs of their students and the characteristics of the context in which they develop their teaching work (Hernández-Leo et al., 2017; Kerr, 1981; McKenney et al., 2015). Teachers continuously formulate and deal with design problems; thus, some authors advocate for considering teaching as a design science (Jordan, 2016; Laurillard, 2013; McKenney et al., 2015). However, preservice teacher training is rarely postulated as design education; in general, teachers are not equipped with the appropriate skills to carry out this complex task (Hernández-Leo et al., 2017; Hoogveld et al., 2005; Laurillard, 2013; Torra et al., 2012; Vigo & Soriano, 2014).

One approach to address this situation is to adapt the design field and design thinking (DT) in its broadest sense so that preservice teachers receive complete training that addresses creative development and enables them to address complex challenges they will face in their daily work in educational centres. In this paper, we assess whether the application of DT in a project-based learning (PjBL) subject helps preservice teachers develop skills to create well-founded and quality instructional materials from a creative, critical, and teamwork perspective.

2. Literature review

2.1. Design thinking (DT)

DT is a perspective of thinking based on the formulation and resolution of complex problems through an analytical and creative human-centred process, which involves people from the beginning (Brown, 2008; Carroll, 2014; Dorst & Cross, 2001; Howard et al., 2008; Mosely et al., 2018; Razzouk & Shute, 2012). This process is materialised by methods focused on addressing user needs, making them an active part of the creation process (Blanco, 2016).

The current DT concept stems from traditional design theories applied in industrial design practice (Razzouk & Shute, 2012). Different methodologies have been collected under DT (Brown & Wyatt, 2010; Design Council, 2020; Stanford University Institute of Design, 2020), which generally consist of three main phases: inspiration, ideation, and implementation (Brown & Wyatt, 2010). Inspiration consists of exploring and identifying the problem or challenge through research and observation. Ideation is a creative process to address the challenge detected. Implementation turns ideas into actions. In all these phases, there are two main types of thinking: the convergent, which moves in one direction and searches for a certain answer or solution, and the divergent, which moves in various directions and poses new strategies to address the situations (Dym et al., 2005). Thus, DT achieves a balance between convergent and divergent thinking and fosters both perspectives (Elwood et al., 2016; Gu et al., 2019; Hadar & Tirosh, 2019).

Although the DT phases or spaces are described in a linear and predefined manner, DT is a multifaceted, messy, and complex process (Brown & Wyatt, 2010; Dym et al., 2005; Teal, 2010). In fact, DT is an iterative process that repeatedly reformulates the problem to find its core and then analyses possible solutions to find the most favourable, allowing for the creation of 'creative bridges' between problems and solutions (Cross, 2011; Dorst & Cross, 2001). DT may seem chaotic at first, but during the project, participants come to understand the process, see the meaning, and achieve more reflective results (Brown & Wyatt, 2010). For this reason, the figure of an appropriate facilitator is essential.

The design approach implies differential advantages related both to the manner of creatively approaching the problem, as well as the efficiency, affordability, and adaptability of its tools. Thus, DT have been actively applied in fields outside design (Blanco, 2016; Dorst, 2010; Mosely et al., 2018), such as engineering, business environments, education, and medicine (Lindberg et al., 2011; Lor, 2017; Marín et al., 2019; Martin & Martin, 2009; Razzouk & Shute, 2012). The visual base of its tools offers a universal language that, properly used, constitutes a great way of communication and thinking. Nonetheless, this advantage has led to a certain over-simplification of DT, due to under-prepared facilitators and courses (Blanco, 2016; Lindberg et al., 2010). For these reasons, although the DT looks extremely accessible, we advocate for experienced facilitators, developers with solid foundations in design, hybrid projects with experts in the different fields, and the investigation and analysis of the environment and its participants: in this case, DT in education.

2.2. DT in education

As mentioned, DT is increasingly relevant in education because it allows students to develop soft skills (Goldman & Zielezinski, 2016; Howard et al., 2008; Lor, 2017; Luka, 2014; Mosely et al., 2018; Naghshbandi, 2020; Wright & Wrigley, 2017) such as collaboration, problem-solving, or innovation (Brown, 2008; Razzouk & Shute, 2012). Among these competences, creativity stands out; creativity is the ability to solve problems and is one of the most important 21st-century thinking skills (Ahmadi et al., 2019; Collard & Looney, 2014; Guo & Woulfin, 2016; Henriksen et al., 2016; Mishra & Mehta, 2017; Nakano & Wechsler, 2018).

In this sense, many authors relate creativity to design and recognise DT, per se, as a creative process (Elwood et al., 2016; Henriksen et al., 2017; Hernández-Leo et al., 2017; Jordan, 2016; Koehler & Mishra, 2005). DT creates an effective framework to promote creativity as a boundary-crossing element and foster open-mindedness in students (Mosely et al., 2018; Page & Thorsteinsson, 2017).

This implies that the application of DT in schools is widespread at several educational levels, from the early years to the university (Pande & Bharathi, 2020). In the first grade of primary school, for example, Coleman (2016) presents a research project to design a better house for the Three Little Pigs. Grammenos and Antona (2018) describe an intensive interactive and participatory course with children, whom they call 'Future Designers', which aims to introduce them to the concepts and practice of creativity, design, and DT for fifth and sixth grades. Carroll et al. (2010) analyse the learning experience of middle school students when applying DT. Scheer et al. (2012) evaluate and analyse DT as a teaching method for high school students. At the university level, DT has been applied in various fields of knowledge such as engineering specialities (Blanco et al., 2017a; McKilligan et al., 2017), and teaching (Jordan, 2016).

Several investigations have introduced design-based pedagogies in training teachers (Elwood et al., 2016; Henriksen et al., 2017; Hernández-Leo et al., 2017; Jordan, 2016; Kali & Ronen-Fuhrmann, 2011; Stevenson et al., 2019). These investigations defend the integration of DT in education from the core, making teachers able to identify problems and develop solutions in the educational environment. This connection between teaching and design reinforces the concept of teachers as designers (Bennett et al., 2017; Elwood et al., 2016; Henriksen et al., 2017; Hernández-Leo et al., 2017; Kirschner, 2015; Mishra & Koehler, 2006; Norton & Hathaway, 2015).

There is a broad discourse and a growing interest in the use of DT in teacher education. However, investigation and knowledge are still lacking (Elwood et al., 2016; Henriksen et al., 2017; Hernández-Leo et al., 2017; Jordan, 2016; Lor, 2017; McKenney et al., 2015). On a practical level, teacher training in the design area is not reflected because the programmes do not normally include this type of training (Elwood et al., 2016; Gleason & Cherrez, 2021; Henriksen et al., 2017; Jordan, 2016; Kali et al., 2015; Kerr, 1981; McKenney et al., 2015). This lack of design training implies that preservice teachers are usually novices; they have no previous design experiences and do not know basic design patterns to apply in the future (Elwood et al., 2016). Therefore, scientific bases, approaches, and tools should be provided from DT, proposing practical solutions to be applied and integrated naturally in preservice teacher training. This training will allow preservice teachers to develop soft skills, apply this discipline properly in their future teaching work, and provide solutions to the complex problems they face in their daily work, such as creating instructional materials, lessons, and learning experiences.

2.3. *Relationship between DT and project-based learning (PjBL) approaches*

Other methodologies, such as PjBL, are frequently found in preservice teacher training programs. PjBL is a method in which the students apply, develop, and learn concepts through collaborative work while solving a problem that may or may not be established (Blumenfeld et al., 1991; Chang & Lee, 2010; Kokotsaki et al., 2016). This method allows the development of 21st-century skills because it promotes problem-solving, communication, teamwork, and leadership (Häkkinen et al., 2017; Tsybulsky & Muchnik-Rozanov, 2019).

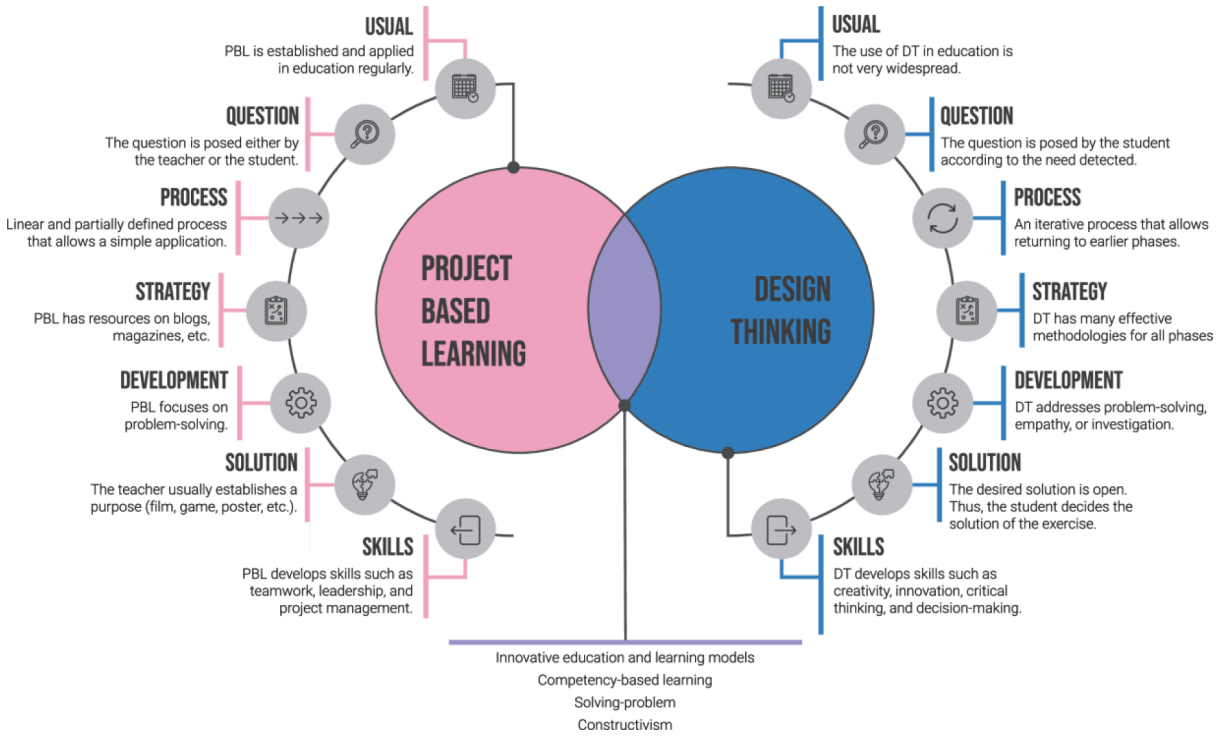

Fig. 1. Characteristics, differences, and similarities between PjBL and DT.

DT and PjBL share a systematic approach focused on finding innovative solutions to problems; both adopt a constructivist learning approach, which is essential for teacher training programs (Dag & Durdu, 2017); and both are requested models for competency-based teaching and learning (Goldman & Zielezinski, 2016; Stokholm, 2014).

However, to establish the scientific basis of this research, it is necessary to identify some fundamental differences between DT and PjBL that can significantly influence preservice teacher training. Fig. 1 shows the differences between both fields, derived from the studies of Elwood et al. (2016), Goldman & Zielezinski (2016), McIntosh (2012), Melles et al. (2015), and Stokholm (2014). These differences are grouped by categories, such as process developed, solution reached, or the skills developed by the students. PjBL begins with a problem or question posed either by the teacher or the student, often related to the curriculum, and establishes a partially predefined route. In contrast, DT allows students to identify, formulate, and frame problems based on research and personal experiences and then answer these problems through non-linear strategies, involving people and without having a goal in mind. Although both perspectives engage similar skills, DT focuses more on experiential learning and developing skills related to posing and identifying problems, empathy, and creative thinking, whereas PjBL attends more to the learning of knowledge and skills such as project management and development.

We consider the models to be complementary and that using the PjBL framework with a subject can help integrate DT naturally. Specifically, we propose training preservice teachers in DT to enable them to formulate problems related to the particular needs of their classroom and to create instructional materials to answer those problems.

In this paper, we present the basis and application of a developed methodology called 'Think-Create-Teach' (TCT). The TCT methodology is evaluated using quantitative methods with an experimental group of preservice teachers to create instructional materials guided by DT. The work processes and instructional materials developed by the experimental group are compared to a control group that did not use TCT. The quantitative results are supported by qualitative methods to understand the reasoning behind them and enrich the interpretations. The application and assessment aim to answer if TCT is adequate to support preservice teachers to formulate and answer their own problems by creating instructional materials guided by DT. Five assessment dimensions related to TCT are studied to answer this research question:

D1. Incorporation and adaptation to the teaching curriculum.
D2. Material suitability.
D3. Work process and instructional material developed.
D4. Emotions and climate.
D5. Perceived contributions.

3. Materials and methods

This article presents the TCT methodology aimed to train preservice teachers in DT. This methodology is developed by an x-disciplinary team and is evaluated in a real environment with preservice teachers.

3.1. Context and participants

Applying DT is not a straightforward task. DT needs to be adapted for its inclusion in the preservice teacher training environment. It is not enough to apply the same perspectives as in the field of design; it is necessary to make changes and adaptations, such as nomenclatures, technical language, objectives, or results. In this environment, complex and transcendent in equal parts, a high level of x-disciplinarity is required. X-disciplinarity is a term assigned to the set of possibilities of collaborative work: multi-, cross-, inter-, and trans- (Blanco, 2016). Thus, an x-disciplinary workgroup was formed by two teams. One team comprised three specialists in design and technology, with experience in research projects for more than 15 years, and facilitators in DT training both in the professional environment and in training environments, as university lecturers in design and technology specialities. The other team was two specialists from the educational field, with more than 15 years working on projects in didactics and school organisation and extensive experience in training preservice teachers as university lecturers. The full x-disciplinary team worked together and listened to all voices, both in creating and developing TCT and in its assessment.

The x-disciplinary group chose a real environment with preservice teachers to apply TCT. Specifically, the subject of 'Instructional Materials and Resources' of the education degree of the Faculty of Education of the University of Zaragoza, Spain. This subject is taught in the second year and is compulsory for all preservice teachers. The subject deals with the study of didactic resources and how to create them according to real classroom needs from schools assigned to the preservice teachers, who, in this experiment, are learning to teach preschool children.

A total of 108 preservice teachers aged 19-21 years participated in the study, of which 96 were female, and 12 were male. This initial sample was divided into two groups, the experimental group and the control group, which were randomly selected. The experimental group was comprised of 56 preservice teachers who applied the TCT methodology to develop their instructional materials. The control group was formed by 52 preservice teachers who did not use the TCT methodology and used the method from previous years instead based on PjBL. The participants in both groups had completed the first year of the education degree and had received the same training to face the subject; they knew educational practices, the types and classifications of instructional resources, as well as teamwork skills but were considered novices in the design and creation of educational resources.

It was ensured that both groups were subjected to as similar experimental conditions as possible. The objective of the subject project was the same for both groups: 'Design and develop an innovative instructional material to use and apply it in a real classroom,

which has to be consistent and aligned to the curriculum and facilitate teaching-learning'. For this, both groups were provided with 16 weeks of time and were divided into teams of 3 or 4 members, which according to Oakley et al. (2004) is the optimal number of members. Thus, the experimental group consisted of 15 groups, and the control group consisted of 14 groups. In addition, both groups (experimental and control) attended the same subject theory classes and received the same number of compulsory tutorials for guidance.

The method used to accomplish the subject project in previous years and during this course in the control group was inspired by PjBL. For its implementation, each of the 14 groups was assigned to a local preschool class and a teacher. This teacher requested a specific material from a list of materials defined by the lecturers (e.g., a light table, a sensory path, etc.). Thus, the challenge faced by the preservice teachers in the control group was defined according to a need posed by the assigned teacher. In addition, at the beginning of the project, each of the teams received a brief to be completed during the project.

The first point of this brief aimed to make preservice teachers reflect on what they knew about the request from the assigned teacher and what did not know and had to determine by research. Then, each group had to search by internet, blogs, Pinterest, or magazines for inspiration, considering the requirements provided by the assigned teacher. Subsequently, based on this research, the groups had to work on their solution and share their progress and difficulties with the lecturers in two compulsory tutorials of 30 minute each. In these tutorials, lecturers provided them with feedback, answers, and guidance to continue the project and, if they wished, they could request further tutorials during the lecturers' regular tutoring hours.

According to the brief, the groups had to present a final instructional material and a report to the lecturers. They had to include the purpose and function of the instructional material and the pedagogical objective and skills addressed. In addition, they had to incorporate photos of the process of instructional material development and its application in the classroom. Finally, they had to conclude with a reflection of the preservice teachers on the value of the project.

3.2. Rationale and development of TCT by the x-disciplinary team

Considering this context, and based on the favourable PjBL framework, the five members of the x-disciplinary group participated in six group sessions for the integration of DT in preservice teachers training. During the meetings, the design team contributed its knowledge about this discipline and the direction and evaluation of projects; the educational team contributed its experience in terms of teaching, the preservice teachers' archetype characteristics, the pedagogical bases, and the curriculum.

During the first session, the motivations, concerns, and visions were established. Each of the project stakeholders, representing design and education, provided their perspective. In line with Blanco (2016), establishing the motivations of each part (shown in Table 1) provided a project overview and helped improve communication, relationship, and esteem between members.

To support the TCT rationale, the design team examined the different models included under DT. According to the experience of the educational team, preservice teachers spend years working on convergent thinking, and there was a shared interest in promoting divergent thinking in their training, for example by creating innovative instructional materials. Considering this interest of stressing the importance of merging divergent and convergent thinking, and thanks to the experience of the design team, it was determined to support TCT on the DT model 'Double Diamond' (Design Council, 2020). As its name indicates, this model is composed of two diamonds; the first diamond implies exploring an issue deeply (divergent thinking) and then focusing on a challenge (convergent thinking), and the second diamond implies providing different answers to the challenge (divergent thinking) and then defining the solution (convergent thinking). Thus, this model represents and achieves a balance between convergent and divergent thinking, both of which are essential to develop creative soft skills (Luka, 2014; Gu et al., 2019; Page & Thorsteinsson, 2017).

There are a variety of efficient, affordable, and adaptable methods, tools, or techniques to support the DT process. Subsequently, the design team conducted a methodical classification of those DT methods or tools that could be better adapted to the area, considering that the preservice teachers have never been trained before in design. This battery of methods were presented and explained to the educational team in the next session. During this session, the members of the x-disciplinary group discussed the

Table 1
Motivations and concerns of the x-disciplinary team.

Design and technology team	Educational team (lecturers)
What is designing for teachers?	What should preservice teachers (in my classes) learn during the subject?
How do teachers design their materials?	How do we train preservice teachers to design their own materials?
Do teachers feel like designers?	What are preservice teachers learning about the design of materials nowadays?
What amount of training do preservice teachers have about design?	What aspects should preservice teachers develop to create their own materials?
How are the preservice teachers taught to design their own materials?	What is DT?
Is DT compatible with the training of preservice teachers?	Is DT compatible with the objectives of the curriculum?
Is DT suitable for preservice teachers?	Is DT posed according to a pedagogical basis?
How can DT be applied in preservice teacher training?	Will DT work correctly for the online course?
What are DT methods most suitable for this context?	Does DT adapt to the time and the assigned lessons?
Does DT foster competency learning?	Will I spend a lot of effort and time?
Does DT promote different learning from copying or memorisation?	What role will I have to take during the classes?
Does DT help to establish a warm climate of communication?	Will I feel comfortable in my classes?
Will preservice teachers find DT useful to design their own materials?	What are the benefits for me and the people in my classes?
Will they apply DT in the future to design their materials?	How do I assess the preservice teachers in my classes?
Is DT innovative from a scientific perspective?	What will this contribute to preservice teachers in their training and future work?

methods and tools, posing examples that interwoven the TCT methodology. Finally, the team voted to select the most appropriate methods, considering aspects such as the time and resources available, the limited experience of participants in the design, and the application environment and curriculum. The adapted methods, tools, or techniques are described in the 3.4 Section.

For several weeks, one design team member developed the materials based on the conclusions obtained in the previous working sessions and their experience. These materials were presented to the group in digital and tangible formats in four sessions corresponding to the four phases of the TCT methodology. During these meetings, issues such as content and visual appearance were discussed until an agreement was reached. For the content, the design team specified the theory and basis of design, as well as the information structure; the educational team detailed aspects related to adaptation to the educational environment (e.g. terminology, inclusive vocabulary, clarity, prior knowledge, etc.). For the visual aspect of the materials, the design team emphasised graphic issues such as colour theory or grid alignment; the educational team specified the available resources.

3.3. TCT methodology

The result of this work between disciplines was the TCT methodology. TCT is inspired by the DT model 'Double Diamond' and aims to train preservice teachers in design so that, guided by the DT framework, they will be able to formulate their own problems and create their own instructional materials. The methodology includes all the necessary material for its implementation. TCT consists of digital materials, including guide cards, complementary templates to fill and follow the steps, and support materials. Every resource has a neat and simple appearance, adapted to the educational environment. Fig. 2 shows the topics of the 15 guide cards, which are structured in 4 phases, distributed and inspired by the DT model 'Double Diamond'. These guide cards encourage the preservice teacher to use the DT process to design their instructional material.

Fig. 3 shows a sample card indicating the structure and elements designed for consistency. The cards offer recommendations or actions to consider or do before, during, and after the exercises. The 'before' section introduces the preservice teachers and gives them tips for preparing for the task. The 'during' section provides them with recommendations and indications on how to conduct it. Finally, the 'after' section explains how to process and analyse the information collected. Additionally, the complimentary templates are sheets that make the application of theory possible; their main function is to support and optimise the execution of activities. The support materials are tangible or digital resources, such as sticky notes, stickers, stopwatches, markers, etc., aimed to facilitate the preservice teachers' work and to favour the activation of the right side of their brains. Finally, the Trello platform was selected as a shared workspace to collect the TCT methodology in digital format; it allows creating of customisable team dashboards, incorporating files, and organising projects. Specifically, a Trello board enables the creation of movable columns to add editable cards easily, thanks to its visual and intuitive interface.

3.4. TCT application

The TCT application during the project of the subject lasted one semester (16 weeks). Each of the 15 groups in the experimental group was assigned to a local preschool class and teacher. Each group had its own Trello dashboard with the TCT materials. The methodology application had two fundamental supports: (1) Practical and face-to-face workshops for all preservice teacher groups, guided by the two members of the educational team (lecturers) and one member of the design team (facilitator); and (2) the online platform that provided the methodology, allowing preservice teachers to have access at any time and write questions or comments on the cards *in situ*, as well as lecturers to give feedback when it is needed. Fig. 4 details the process of the activities conducted during the application of TCT.

Note that, due to the Covid-19 situation, empirical research was affected and the first support (face-to-face workshops) could be used only during Phase 1. Thus, the preservice teachers had the opportunity to conduct the field research tasks in the assigned educational centres, but in the remaining phases, only the second support was used. Phase 2 was executed through video calls between the members of each group; the lecturers and the facilitator were online to facilitate the process and answer questions if necessary. Likewise, two mandatory tutorials of 30 minutes each were conducted by video call to guide Phases 3 and 4. Additional meetings could

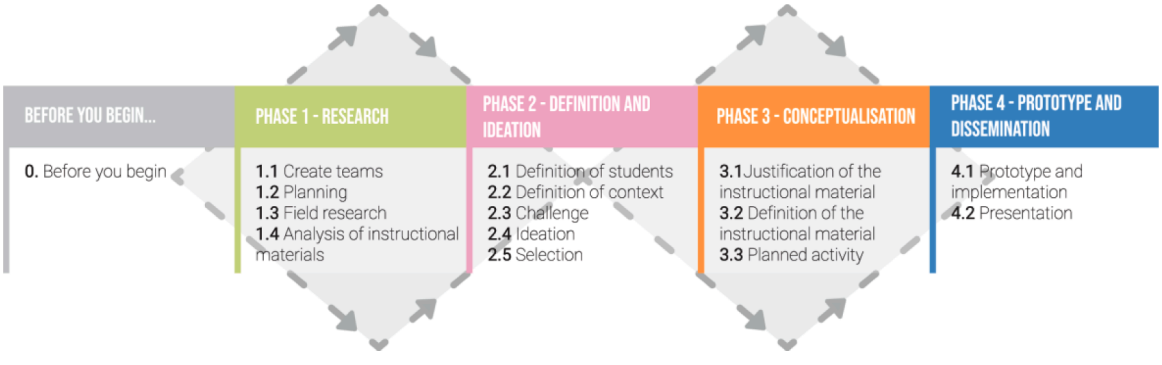

Fig. 2. Phases and cards of the 'Think-Create-Teach' (TCT) methodology.

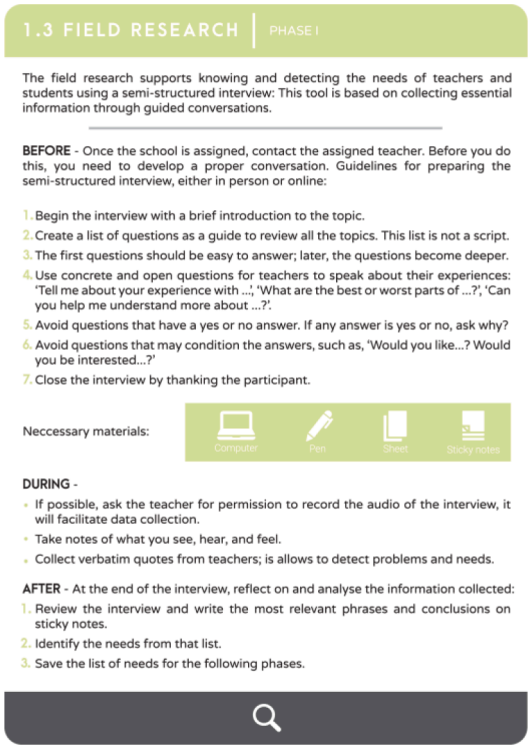

Fig. 3. Example card of the TCT methodology (1.3 Field research).

be scheduled at the preservice teachers' request. The lecturers and the facilitator, who had previously reviewed the work, participated in tutorials to provide feedback. In these meetings, each group of preservice teachers explained their progress and the difficulties detected; then, the lecturers and the facilitator evaluated the findings or results, addressed questions, and guided them to continue with the project.

As can be seen in Fig. 4, at the beginning of the project, a workshop was conducted to introduce TCT and Trello platform, as well as to create and consolidate the 15 groups. Then, the following phases took place:

Phase 1: During the research phase, semi-structured interview and contextual observation were adopted to identify and understand the needs of the teacher assigned, and to know the characteristics of the students and the classroom (user-centric research). After analysing the research conducted and identifying the main need, existing instructional materials related were identified to determine the advantages and disadvantages.

Phase 2: In the definition and ideation phase, the *Personas* method (Pruitt & Grudin, 2003) was adopted to organise, empathise, and define the assigned students' attributes. Then, each group defined its particular challenge, asking questions with 'How could we…?' and considering the users' needs. Finally, brainstorming was used to ideate and answer the challenge posed, avoiding criticism and judgment, addressing only a conversation at a time, building on the others' thoughts, and noting all ideas.

Phase 3: In the conceptualisation phase, sketching was used to convert the initial ideas into a concept of the instructional material, defining dimensions, materials, shapes, or features. Some basic modelling and illustration tools were shown to the preservice teachers to encourage them to show the material definition as realistically as possible. Then, the *Five Whys* technique (Serrat, 2017) was adapted to the *Five Whats* to justify the instructional material, specifically: (1) what is the main function, (2) what is the most related curricular area, (3) what is the content, (4) what are the didactic objectives, and (5) what skills works on. After defining the instructional material, the *Storyboard* (Van der Lelie, 2006) was adopted to define and show the implementation of the material in the classroom and to reflect on the planned activity.

Phase 4: In the prototype and dissemination phase, a prototype of the instructional material was developed for application and assessment in the class assigned. Due to the Covid-19 situation, the preservice teachers could not conduct the experiment and assessment; however, the instructional material developed was sent to the teacher assigned, who provided feedback. In addition, guidelines for creating visual and structured presentations were provided to disseminate the process and the result. Each group exhibited their material over a video call to the lecturers, the facilitator during project development, and the preschool class teacher from the educational centre.

3.5. TCT assessment

In the stage of the assessment, quantitative analyses were conducted in order to determine the application of the TCT in terms of

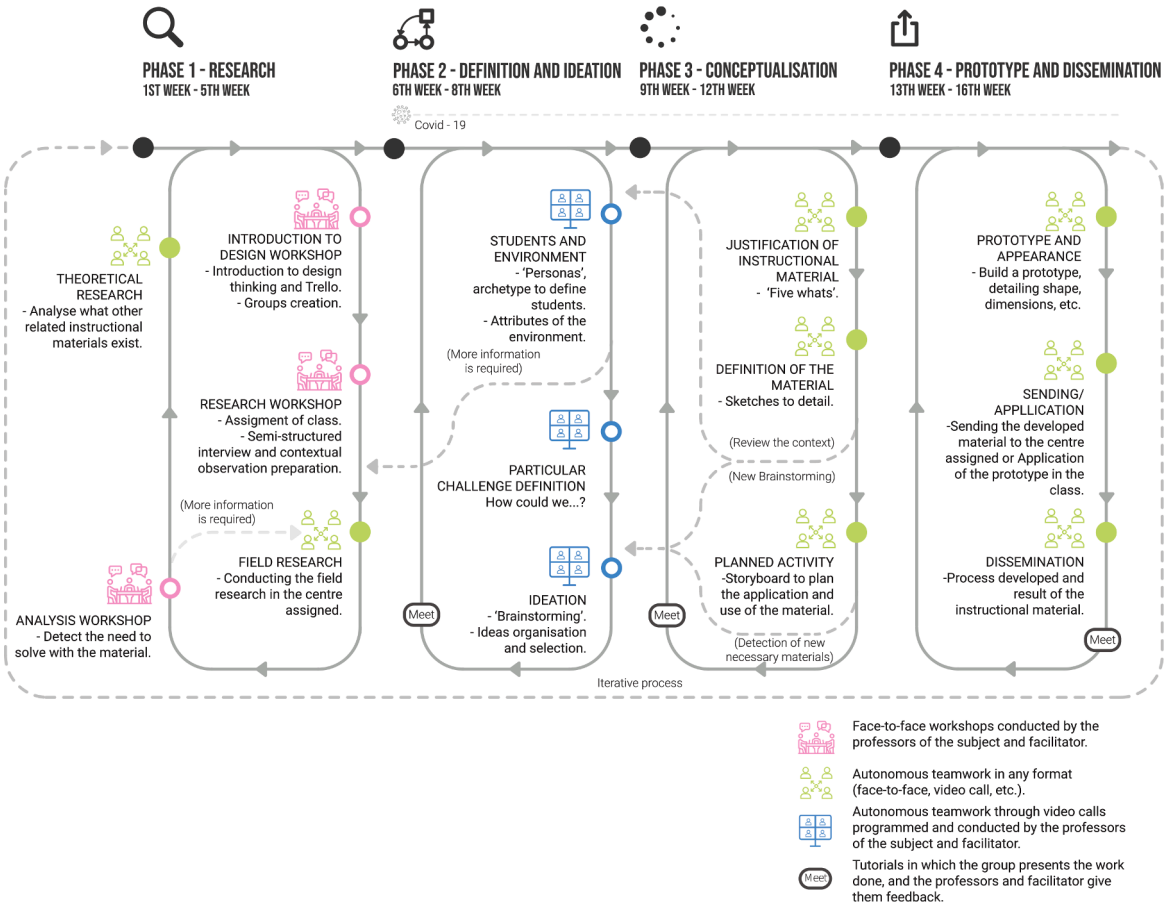

Fig. 4. TCT application process.

participants' perceptions of the 5 dimensions determined. However, in assessments with real users and real environments, exclusively quantitative approaches have interpretative weaknesses and mixed-methods approaches can help to overcome them (Blanco, 2016). Thus, complementary qualitative information was collected to understand the reasoning behind, enrich the interpretations, and support the Discussion section.

The Xassess evaluation methodology (Blanco, et al., 2016) was applied to study the assessment dimensions D1-D5. It is a validated evaluation method that merges quantitative and qualitative approaches; it is centred in multidisciplinary teams and includes the perspectives of all the disciplines involved in the project, considering the assessment from the initial stages of the project.

Starting from the Blanco et al. (2016) theoretical assessment framework, Xassess allows adapting the evaluation strategy to the idiosyncrasy of the education scenario, focusing on the collaborative analysis offered by different perspectives. Thus, part of the x-disciplinary group, specifically the two members of the educational team (lecturers) and one of the design team members (the facilitator during project development), assessed the use of TCT by de preservice teachers (experimental group) through a survey with closed and open questions, the project management platform, as well as observation, field notes, and periodic internal discussions. They also conducted a comparative study of the work processes and instructional materials of the experimental group using TCT (see 3.4) and those of the control group using the traditional method (see 3.1). In turn, the preservice teachers in the experimental group assessed TCT through their opinions. Finally, the educational team (lecturers) was assessed by the design and technology team through a semi-structured interview, as well as observation, field notes, and periodic internal discussions.

This is reflected in Table 2, which shows the overall dimensions to assess (aimed to answer the research question), including indicators (specific concepts that disaggregate the dimensions), techniques applied during the experimentation, and the actors and scenarios involved. The assessment was conducted following relevant ethical guidelines (Lodico et al., 2010), providing a verbal and written explanation and obtaining consent from the participants. Thus, before starting with the survey, the preservice teachers had to agree to a statement, which informed them about the purpose and assured them of the privacy and confidentiality of the data they provided.

Following the TCT evaluation process, Table 3 defines the assessment techniques: the data collection methods and subsequent analysis. The Xassess methodology ensures the reliability and validity of the evaluation at a methodological level by evaluating the same assessment dimension in different manners (Table 2). Similarly, the questions were carefully formulated during the preparation

Table 2
Dimensions, indicators, and techniques to answer if TCT is adequate to support preservice teachers to formulate and answer their own problems by creating instructional materials guided by DT.

Assessment dimension	Perspective	Indicator	Technique
D1. Incorporation and adaptation to the teachingcurriculum	Lecturers	TCT adequacy to the curriculum objectives TCT adequacy to the available time and resources TCT flexibility to be adapted to PjBL TCT ability to work specific and boundary-crossing competences of the degree Difficulties detected during its adaptation and application	Observation, field notes, and periodic internal discussions Semi-structured interview
D2. Material suitability	Lecturers	Lecturer acceptance: perspectives about the methodology, cards, and resource usage by the preservice teachers Opinion about design techniques in education	Observation, field notes, and periodic internal discussions Semi-structured interview
	Preservice teachers	Preservice teachers acceptance: perspectives about the methodology used Opinion about cards and resources	Observation, field notes, and periodic internal discussions Survey (closed and open questions) Project management platform
D3. Work process	Lecturers	Amount of information collected by preservice teachers Quality of each of the tasks performed Feedback given to preservice teachers Comparison with the projects developed without TCT	Observation, field notes, and periodic internal discussions Semi-structured interview Project management platform
	Preservice teachers	Reflection on the work process developed	Survey (closed and open questions)
D3. Instructional material developed (Result)	Lecturers	Assessment of instructional materials according to coherence, adequacy, safety, quality, usage, accessibility, and creativity. Comparison with the materials developed without TCT	Observation, field notes, and periodic internal discussions Semi-structured interview Project management platform
	Preservice teachers	Reflection on the material developed	Survey (open question)
D4. Emotions and climate	Lecturers	Attitudes and dialogues between lecturer–preservice teacher, preservice teacher–preservice teacher, preservice teacher–lecturer Covid-19 situation	Observation, field notes, and periodic internal discussions Semi-structured interview
	Preservice teachers	Perception of how they felt in class (pre-post) Covid-19 situation Comparison with other subjects during Covid-19	Observation, field notes, and periodic internal discussions Survey (closed and open questions)
D5.Perceivedcontributions	Lecturers	Opinion about classes and methodology TCT contribution TCT utility Suggestions to improve the methodology Comparison with other methodologies Use TCT in the next course	Observation, field notes, and periodic internal discussions Semi-structured interview
	Preservice teachers	TCT contribution TCT utility Suggestions to improve the methodology Comparison with other methodologies Use TCT in future work	Observation, field notes, and periodic internal discussions Survey (closed and open questions)

of the interview and survey to avoid introducing bias. This effort was invested to not affirm preconceptions of the researchers and prevent the Hawthorne effect, that is, the tendency for interviewees to respond positively due to the special treatment they receive from the evaluator (Adair, 1984; Diaper, 1990). Finally, different specific aspects detailed in Table 3 were considered to ensure reliability in data collection and data analysis.

These evaluation tools allowed us to collect the findings described in the following results and discussion sections.

4. Results

This section includes the quantitative results of the assessment organised according to the assessment dimensions shown in Table 2. Note that the results of this study mainly come from the application of TCT in the experimental group; the scope of the comparative with the control group is limited to the assessment dimension of the work process and instructional material developed by preservice teachers.

4.1. Material suitability – cards

Fig. 5 shows the cards of the TCT methodology and includes information related to four factors. The first factor (green) is the number of groups with questions about each card; 66.6% of groups (calculated as 10 of 15, see Fig. 5) had questions about 1.4 Analysis of the materials, and 60% had questions about 2.1 Definition of the students. Other cards that raised questions were 2.3 Challenge

Table 3
Data collection and Data Analysis.

Technique	Data Collection	Data Analysis
Semi-structured interview (Qualitative)	The semi-structured interview allowed collecting experiences and opinions of the educational team (lecturers). Both lecturers were interviewed separately before starting to work in the x-disciplinary group and again after applying the TCT methodology in the classroom. The interviews lasted approximately 1 hour each and were recorded and transcribed by a design and technology team member. The first interview aimed to know the accumulated experiences during their years of teaching. The interview began with an open question, specifically: What is 'designing' for you (for teachers)? From this beginning, an open conversation was conducted. The second interview aimed to know the experience and opinion after the application of TCT in their subject, as well as to assess the specific and boundary-crossing skills of the subject and the degree that TCT works. The interview included questions such as: How would you define the material used during the project? How would you define the preservice teachers' attitudes towards TCT? This interview also reviewed the official documents of the subject and degree.	The interviews were transcribed and coded according to the thematic analysis approach (Patton, 2014), and using the dimensions shown in Table 2 as themes. The full transcriptions were sent to the educational team for review (Merriam, 1988) and were read several times separately by each of the three technical evaluators of the design and technology team. Then, a 2-hour session in which researchers discussed their reflections was conducted. In this session, the researchers agreed to justify their suggestions with verbatim quotations to avoid inserting their judgments or beliefs without data from the research. In cases of disagreement, the issue was continued until the team reached full agreement.
Survey (Quantitative and qualitative)	Two surveys were used to collect the experiences and views of the 56 preservice teachers (experimental group): the first one (pre-survey) was conducted before starting the project, and the second (post-survey) at the end of the project. The pre-survey aimed to know the participants' expectations and prior design knowledge. Some of the questions were: What do you expect from the subject? What is designing for you? How do you expect to feel during the project? The post-survey aimed to know the experience after the use of TCT, and it was divided into six sections: control questions, methodology contribution, methodology improvements, comparison with other methodologies, Covid-19 situation, and emotional responses. Some of the questions were: What cards have you found the most useful and what the most complicated? Would you like to use this methodology or any of its phases again?	The surveys were conducted through the Google Forms platform and included closed and open items, as well as Likert scales with a score of 0 to 7. The resulting data were exported to MS Excel. Closed (quantitative) questions were analysed using descriptive statistics and visual graphics. These graphics were made with the Python 3.8 language and the pandas, matplotlip, and seaborn libraries. Then, to detect significant differences and make statistical inferences, the data were analysed using the IBM SPSS Statistics Version 24.0 software. For this purpose, the normal distribution of the data was studied and non-parametric tests were used. In addition, open questions (qualitative) were manually coded by the evaluators according to similarities in the reflections made by the preservice teachers. Subsequently, each group was named with a phrase to describe the content. From each group, a summary was written that included verbatim quotations.
Observation, field notes, and periodic internal discussions (Qualitative)	During the TCT application, the educational team (lecturers) and a member of the design team (facilitator) acted as evaluators, conducting observations and taking field notes in a non-intrusive manner. All these observations were shared in the 'periodic internal discussions' (see Table 2), which consisted of 15-minute sessions between the members of the x-disciplinary group, organised at the end of each class. In each session, the group discussed issues such as: What attitude did the preservice teachers have? How much interest had they shown? What questions had arisen? What had surprised them?	During the 'periodic internal discussions' in which the field notes were discussed, the x-disciplinary team created short records of the meetings to collect the key concepts shared. These annotations were used as support for the rest of the conclusions obtained through quantitative techniques.
Project management platform (Quantitative)	In addition to serving as a platform for the methodology, Trello was used as an evaluation tool because the complete process was registered on it. The platform allowed analysing the work process and instructional material developed by preservice teachers (experimental group), as well as the questions of each group, the feedback provided, and the valuation of each guide card.	The quantitative data from Trello were analysed using the sequence followed for the closed questions of the survey. That is, descriptive statistics and visual graphs using Python 3.8 and, to detect significant differences, IBM SPSS Statistics Version 24.0 software. Note that, the work processes and instructional materials developed by the experimental group were assessed and compared with the control group according to the factors established in Table 2 and valued by the lecturers.

(26.6%) and 3.2 Definition of the material (20%). In contrast, the cards that raised no questions were 1.1 Create teams and 2.2 Definition of the context, which coincide with the preservice teachers' tasks in workshops. The second factor (pink) shows the number of groups that received comments (feedback) on that card from the lecturers. The cards with the most feedback were 1.4 Analysis of the materials, 2.1 Definition of the students, and 2.3 Challenge. Additionally, high values are shown for 1.3 Field research, 3.1 Justification of the material, and 4.1 Prototype and implementation, which correspond to the beginning of each phase, and positive comments were made to all groups to encourage them to continue with the work. The third factor (orange) refers to the number of groups that completed the work described on the card incorrectly. Card 1.4 Analysis of the materials was incorrectly performed the most times (73.3%); this agrees with the number of questions and comments on this card. The last factor is the number of groups that did not carry out the card (blue). The only cards not used by one or two groups were 1.4 Analysis of the materials, 2.1 Definition of the students, and

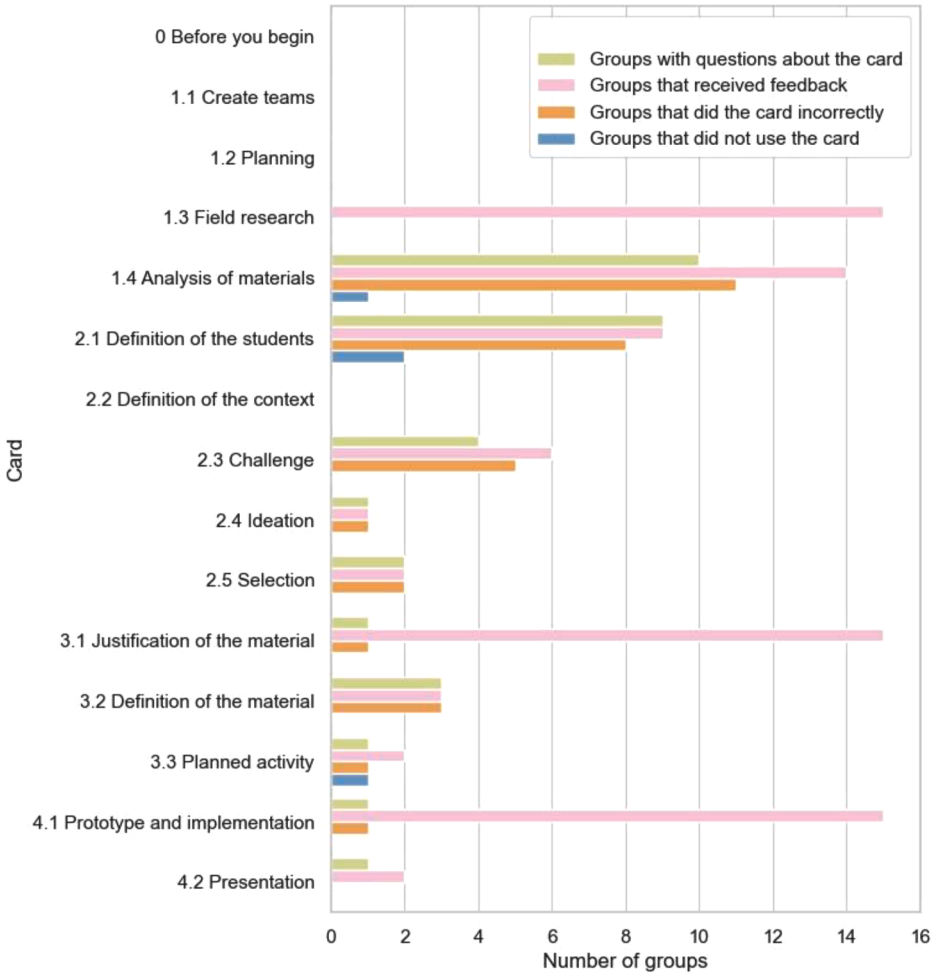

Fig. 5. Assessment of the card execution, from 0 (none) to 15 (all).

3.3 Planned activity.

Fig. 6 shows the TCT methodology cards and includes information about usefulness and complexity. It indicates that 1.1 Create teams was the card least selected as useful by preservice teachers (4.4%) because they knew each other and had worked together before. The card with the next-lowest percentage is 1.4 Analysis of materials, chosen by 22.2% of the preservice teachers. The rest of the cards were chosen as useful by a high percentage: 2.4 Ideation (44.4%), 4.1 Prototype and 4.2 Presentation (both 42.2%.), 3.2 Definition of the material and 1.3 Field research (40%), and 1.2 Planning (37.8%) were the most valued. The cards form a rough bell shape when evaluated in terms of complexity: the cards in the centre of process development were found to be more complex, and the cards at the beginning and the end were less complex. The cards rated as the most complex are 3.1 Justification of the material and 1.4 Analysis of materials (both 33.3%), 2.1 Definition of the students (31.1%), and 2.4 Ideation (26.7 %).

Fig. 7 shows the mean valuation and standard deviation of each of the cards reported by each group of the preservice teachers in the experimental group through Trello after its implementation. The values shown in Fig. 7 are detailed in Table 4.

To determine whether there were significant differences between one card and another, a Shapiro-Wilk normality test was performed, which determined non-normal distributions for most of the variables (cards). Thus, non-parametric Wilcoxon signed ranks tests (for paired samples) were conducted to compare the difference between cards. Then, using Bonferroni's method as the multiple comparison correction (a significance level of $p < 0.00048$), it was found that there was no significant difference between the mean score of any card (see Table 4). Thus, we could say that the average score of all cards is 5.8 ± 0.4. Nevertheless, without considering Bonferroni correction, which is highly conservative (Armstrong, 2014), and using the significance level of $p < 0.05$, significant differences were found in some cards as shown in Table 4.

To simplify this analysis and to find out relationships between phases, the same process was applied, aggregating the cards according to the phases of the TCT methodology. The result is shown in Table 5, and it can be seen that Phase 4 (without Bonferroni correction) had a significantly higher score than Phase 0 ($p = 0.010$) and Phase 1 ($p = 0.028$). No significant differences were found with the Bonferroni correction.

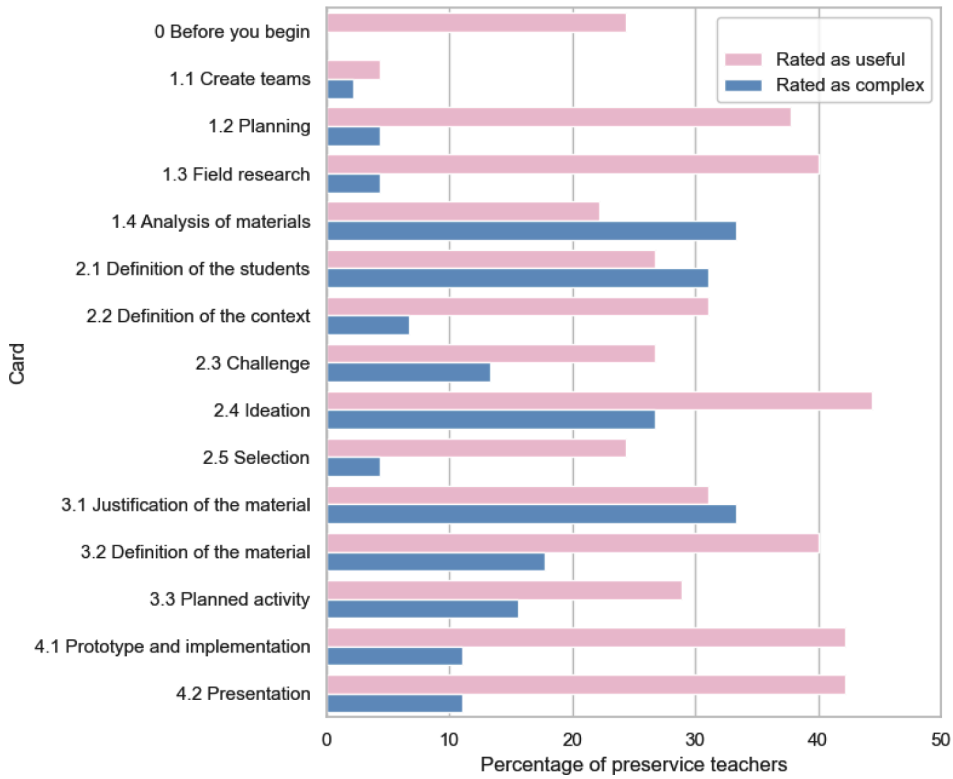

Fig. 6. Assessment of the usefulness and complexity of the cards. From 0 (no preservice teacher selected the card) to 56 (all preservice teachers selected the card).

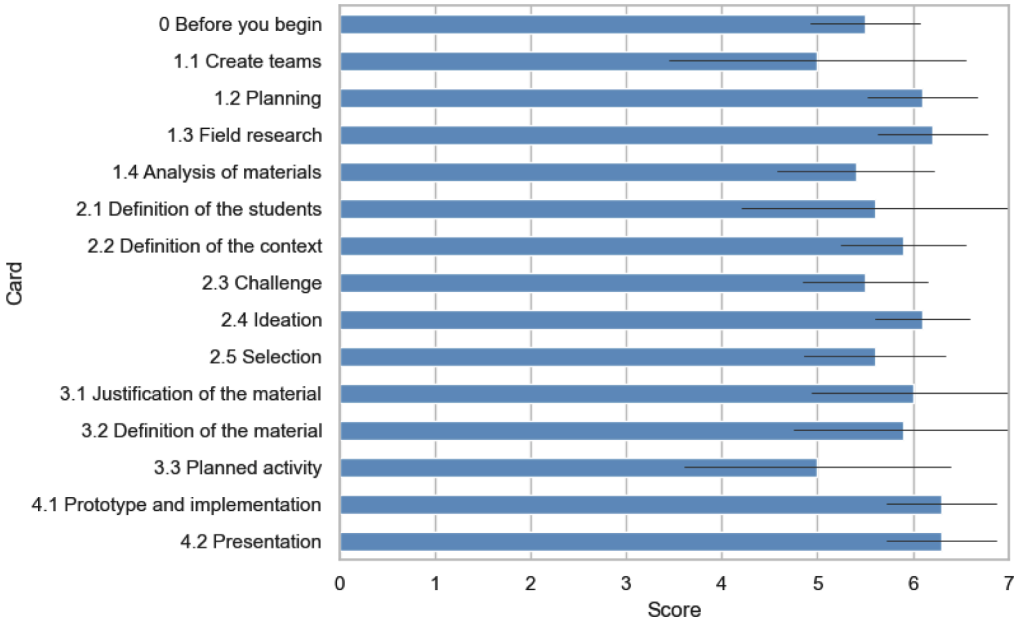

Fig. 7. Card valuations reported by preservice teachers (mean and standard deviation detailed in Table 4). Scores range from 0 (minimum valuation) to 7 (maximum valuation).

Table 4
Statistical results of card valuations reported by preservice teachers.

Card	Score	P-value - Wilcoxon test												
	$\mu \pm \sigma$	0.0	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	4.1
0.0	5.5 ± 0.7														
1.1	5.0 ± 1.9	0.305													
1.2	6.1 ± 0.7	0.034*	0.026*												
1.3	6.2 ± 0.7	0.011*	0.075	0.739											
1.4	5.4 ± 1.0	0.579	0.439	0.034*	0.026*										
2.1	5.6 ± 1.5	0.527	0.161	0.206	0.273	0.524									
2.2	5.9 ± 0.8	0.114	0.083	0.380	0.288	0.102	0.461								
2.3	5.5 ± 0.7	0.746	0.438	0.026*	0.027*	0.660	0.343	0.038*							
2.4	6.1 ± 0.6	0.041*	0.027*	0.854	0.726	0.055	0.250	0.305	0.026*						
2.5	5.6 ± 0.8	0.655	0.226	0.096	0.066	0.258	0.890	0.227	0.461	0.101					
3.1	6.0 ± 1.2	0.136	0.173	0.931	1.000	0.062	0.446	0.551	0.102	1.000	0.168				
3.2	5.9 ± 1.3	0.200	0.083	0.541	0.546	0.102	0.389	1.000	0.277	0.522	0.305	0.674			
3.3	5.0 ± 1.6	0.290	0.891	0.011*	0.049*	0.437	0.062	0.055	0.250	0.011*	0.201	0.108	0.055		
4.1	6.3 ± 0.6	0.010*	0.062	0.435	0.414	0.026*	0.258	0.205	0.017*	0.343	0.026*	0.528	0.365	0.017*	
4.2	6.3 ± 0.6	0.010*	0.062	0.435	0.414	0.026*	0.258	0.205	0.017*	0.343	0.026*	0.528	0.365	0.017*	1.000

* There are significant differences considering a significance level of 0.05.
** There are significant differences considering the Bonferroni correction: 0.00048 (no one in this case).
Scores range from 0 (minimum valuation) to 7 (maximum valuation). μ: Mean, σ: Standard deviation.
Graphic representation in Fig. 7.

Table 5
Statistical results of card valuations reported by preservice teachers grouped on phases.

Phase	Score μ ± σ	P-value - Wilcoxon test Phase 0	Phase 1	Phase 2	Phase 3
Phase 0	5.5 ± 0.7				
Phase 1	5.7 ± 0.7	0.538			
Phase 2	5.7 ± 0.6	0.259	0.625		
Phase 3	5.6 ± 0.9	0.634	1.000	0.241	
Phase 4	6.3 ± 0.6	**0.010***	**0.028***	0.072	0.074

* There are significant differences considering a significance level of 0.05.
** There are significant differences considering the Bonferroni correction: 0.005 (no one in this case).
Scores range from 0 (minimum valuation) to 7 (maximum valuation). μ: Mean, σ: Standard deviation.

4.2. Instructional material developed by preservice teachers

The lecturers evaluated the materials developed by the preservice teachers in terms of coherence, adequacy, safety, quality, usage, accessibility, and creativity on a scale from 0–5, both in the experimental group and in the control group. These factors came from the teaching guide of the subject, which was established iteratively during previous courses by the lecturers according to their experience and the literature (López & Rial, 2015; Lucas, 2015).

Fig. 8 shows graphically the results of assessing the materials of the experimental group and the control group. The values shown in Fig. 8 are detailed in Table 6. At the descriptive level, it should be noted that the distribution of the perceived safety and quality showed high symmetry between the experimental and control group. For the factors such as adequacy, usage, accessibility, and creativity, the experimental group score was more concentrated, and the control group score was more dispersed.

To study the differences between each of the factors in the experimental group and the control group, due to the absence of normality, the Mann-Whitney U test (for independent samples) was used. The results shown in Table 6 revealed that there were significant differences between the groups in the factors of adequacy ($p = 0.013$), usage ($p = 0.004$), and creativity ($p = 0.025$), being the scores of the experimental group significantly higher.

4.3. Emotions and climate

Fig. 9 indicates the self-reported preservice teachers' thoughts (experimental group) about the programme before starting the course (pre) and after having developed the course work using TCT (post). The values shown in Fig. 9 are detailed in Table 7.

Due to the absence of normality, Wilcoxon signed ranks tests (for paired samples) were used to study the differences between each of the factors in the pre-test and post-test. The results shown in Table 7 of the pre-post tests conducted on the experimental group detected significant differences in the entertained ($p = 0.000$) and motivated ($p = 0.001$) factors. Thus, the preservice teachers were more entertained (4.9 ± 1.1) than they expected to be when starting the project (4.2 ± 0.7). Likewise, the preservice teachers felt less motivated (5.1 ± 1.0) than expected (5.8 ± 1.0), which they justified with the situation of Covid-19.

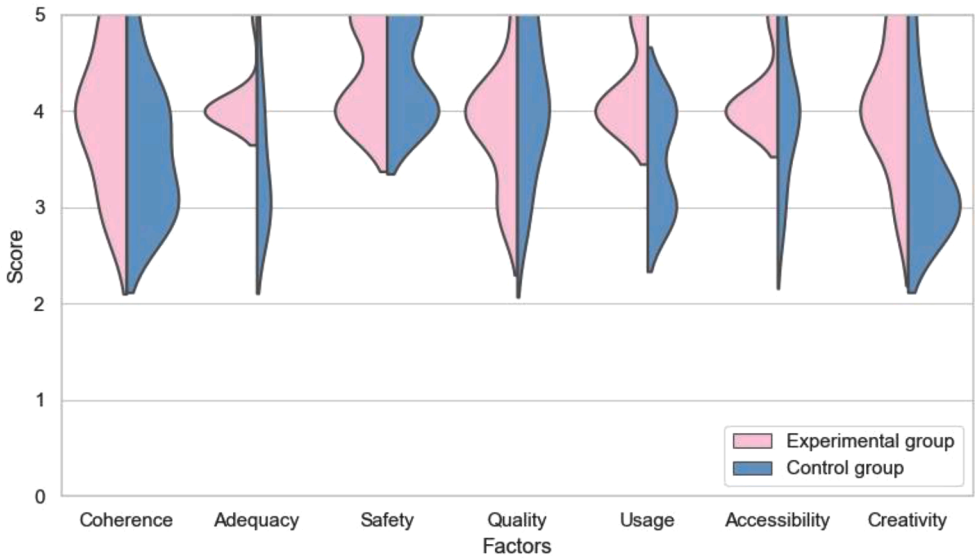

Fig. 8. Assessment of instructional material (mean and standard deviation detailed in Table 6). Comparison between the experimental group and the control group. Scores range from 0 (minimum valuation) to 5 (maximum valuation).

Table 6
Statistical results of the assessment of instructional material. Comparison between the experimental group and the control group.

Factors	Experimental group μ ± σ	Control group μ ± σ	P-value Mann-Whitney U test
Coherence	4.0 ± 0.7	3.6 ± 0.7	0.199
Adequacy	4.1 ± 0.3	3.5 ± 0.7	**0.013***
Security	4.4 ± 0.5	4.4 ± 0.5	0.938
Quality	3.8 ± 0.6	4.1 ± 0.7	0.350
Usage	4.3 ± 0.5	3.5 ± 0.5	**0.004***
Accessibility	4.2 ± 0.4	4.0 ± 0.7	0.499
Creativity	4.1 ± 0.7	3.4 ± 0.7	**0.025***

* There are significant differences considering a significance level of 0.05.
Scores range from 0 (minimum valuation) to 5 (maximum valuation). μ: Mean, σ: Standard deviation.
Graphic representation in Fig. 8.

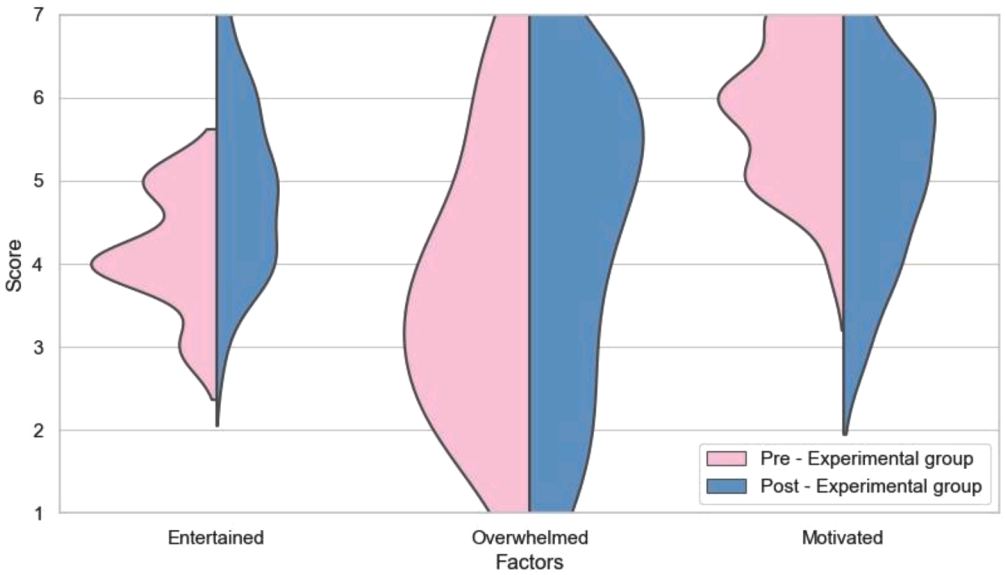

Fig. 9. Assessment of emotional responses (mean and standard deviation detailed in Table 7). Comparison between pre- and post-course. Scores range from 0 (minimum valuation) to 7 (maximum valuation).

Table 7
Statistical results of the assessment of emotional responses. Comparison between pre- and post-course.

Factors	Pre score μ ± σ	Post score μ ± σ	P-value Wilcoxon test
Entertained	4.2 ± 0.7	4.9 ± 1	**0.000***
Overwhelmed	3.8 ± 1.6	4.3 ± 1.8	0.083
Motivated	5.8 ± 0.9	5.1 ± 1.1	**0.001***

* There are significant differences considering a significance level of 0.05.
Scores range from 0 (minimum valuation) to 7 (maximum valuation). μ: Mean, σ: Standard deviation.
Graphic representation in Fig. 9.

Fig. 10 illustrates the results of two questions related to the Covid-19 situation. The first question was 'Do you consider that the TCT methodology aided to develop the subject project in the Covid-19 situation?'. The 77.8% affirmed that TCT helped them develop the work in the Covid-19 situation, compared to 8.9% who did not believe this to be the case. The rest indicated in 'other' that TCT was equally useful with or without Covid-19. The second question was 'Have you noticed differences with other subject projects developed in the same Covid-19 situation?', where 82.2% reported that they had experienced a notable improvement in this subject thanks to the methodology.

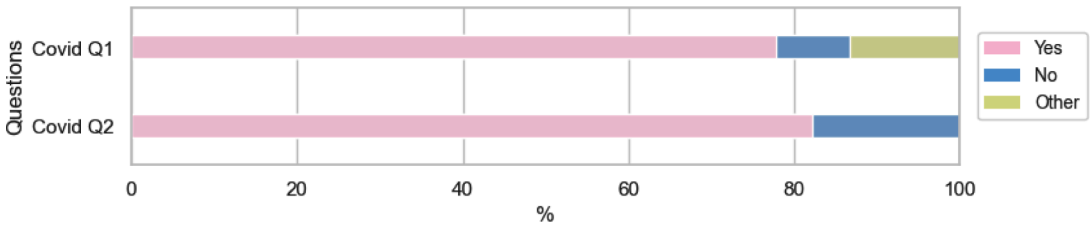

Fig. 10. Covid-19 special situation.

4.4. Perceived contributions

Fig. 11 shows the mean score and standard deviation of three general questions answered by the preservice teachers. The values shown in Fig. 11 are detailed in Table 8. The first was 'How useful has the methodology been to develop the project?' The second was 'Do you consider that the methodology has aided teamwork?' The last was 'Would you like to use this methodology or any of its phases again?'

Due to the absence of normality, Wilcoxon signed ranks tests (for paired samples) were conducted to compare the difference between the answers of the questions. According to the results shown in Table 8, it can be assured that, using Bonferroni correction (significance level of $p < 0.017$), the teamwork-related question (Q2) was scored significantly higher than Q1 ($p = 0.003$) and, without considering the Bonferroni correlation (significance level of $p < 0.05$), was also scored significantly higher than Q3 ($p = 0.025$).

To conclude with the results, according to the questions raised at the end of the survey, note that 97.8% of preservice teachers said that although this method is laborious, it is worth it. Additionally, all preservice teachers (100%) said that the methodology includes all the most important aspects to be considered by a teacher when designing instructional materials.

5. Discussion

To frame the results of TCT methodology, Table 9 summarises studies that describe other relevant and similar tools. For the selection of studies, we applied the following criteria: 1) have a similar pedagogical basis to TCT, 2) focus on teacher training, 3) provide training based on DT. The manuscripts included in this table represent a fundamental basis for the training of teachers in design and were a source of inspiration for the present study.

From the information documented in Table 9, it can be deduced that the potentialities and differences of this study with respect to the literature are: adaptation to the context based on x-disciplinarity, integration into a compulsory subject of the curriculum, assessment using mixed methods (quantitative and qualitative), comparison against a control group, and focus on designing instructional materials.

The research conducted in this study permitted extracting deep and structured conclusions on the experiences of the preservice teachers and the lecturers while using TCT. These findings are presented in the following sub-sections, which are organised according to the assessment dimensions of Table 2. Some findings will be useful to improve TCT, and others may foster creating new resources and new teaching methods focused on training preservice teachers in design.

5.1. Incorporation and adaptation to the teaching curriculum (D1)

TCT is adapted to the subject in timing and scope 'at first, just hearing the idea, I already thought it could fit (...); after the application, I can assert that TCT adapts and contributes to the subject' (lecturer of the subject). According to Calavia, Blanco, & Casas, 2021, this adaptation is essential because 'incorporation' and 'adaptation' to the curriculum are the first premises to consider when developing an instructional material to ensure its viability in the classroom. In this manner, the TCT integration is justified for two reasons. The first reason is that the subject where TCT was inserted used PjBL previously, and the symbiosis between PjBL and DT described in the introduction makes the inclusion natural. The second reason is that, in line with Blanco et al. (2016), creating an x-disciplinary group including the lecturers (educational team) from the beginning made it easier to adapt TCT to the environment.

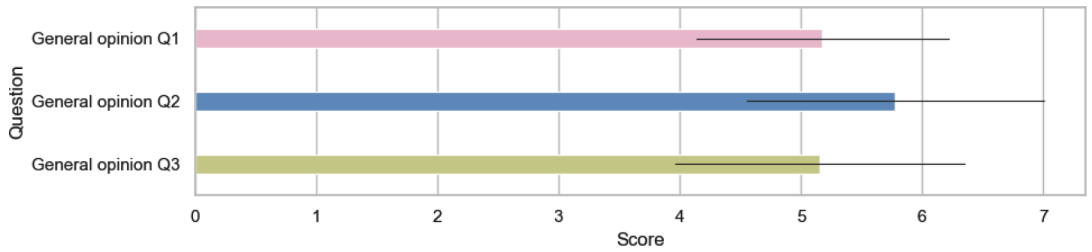

Fig. 11. Perceived contribution score (mean and standard deviation detailed in Table 8). From 0 (minimum valuation) to 7 (maximum valuation).

Table 8
Statistical results of the general opinion.

Questions	Score μ ± σ	P-value - Wilcoxon test Q1	Q2
General opinion Q1	5.2 ± 1.1		
General opinion Q2	5.8 ± 1.2	**0.003****	
General opinion Q3	5.2 ± 1.2	0.953	**0.025***

* There are significant differences considering a significance level of 0.05.
** There are significant differences considering the Bonferroni correction: 0.017.
Scores range from 0 (minimum valuation) to 7 (maximum valuation). μ: Mean, σ: Standard deviation.
Graphic representation in Fig. 11.

This leads us to affirm that the resulting tool fits into the educational environment described and is designed so that the x-disciplinary team is not strictly necessary in the future.

Despite the positive findings, applying TCT in the real environment involved a great effort for the team. The team dealt with the materials preparation, planning, class development, results from the assessment, as well as with restricted hours, available materials, and a high number of students. In this sense, one of the lecturers indicated, 'at the beginning a facilitator is needed because we are not trained in design (…) you give us that vision of design (…) nevertheless, I have noticed great improvements in myself since we started'. Consequently, the facilitator, who should ideally have university studies in design (Wright & Wrigley, 2017), can encourage the use of DT by teachers and students, in line with Mosely et al. (2018).

Note that TCT, like the PjBL approach, uses the competency-based educational approach; one of the lecturers assured that 'the methodology leads them to develop competences such as teamwork, critical thinking, divergent thinking or mental structure'. In fact, the preservice teachers noted a contribution of teamwork skills significantly higher compared to the other contributions (see Table 8). Analysing the subject and degree documentation with the educational team (lecturers) affirms that several specific and boundary-crossing competences included in this documentation are used. Applying TCT allows the incorporation of new degree competences that were not previously used in the subject. Specifically, these competences are aligned with the cooperative work to construct learning spaces and innovative instructional materials that improve the teaching work and adapt to the context characteristics and the preschool students; and fostering actions outside the university and making students investigate, manage, analyse, and communicate information effectively, critically, and creatively (teaching guide of the subject). However, assessing this competency-based learning is not easy (Geisinger, 2016; Toomey et al., 2017). In this case, we rely on what we call 'evaluation of competences by design', which is based on naturally guiding students in a series of steps that lead them to develop teamwork, analysis, empathy, divergence, participation, motivation, decision-making, reflection, redefinition, or dissemination, according to Calavia, Blanco, & Casas, 2021. Thus, it does not seek to 'measure' the development of competences in students; but, in line with Calavia, Blanco, & Casas, 2019, make sure that these competences are used.

5.2. Material suitability (D2)

The design and technology team had a relevant influence on the development of the TCT material. Additionally, thanks to the possibilities offered by new technologies to create and share content (Henriksen et al., 2016; Lombardi, 2007), the methodology was digitally supported on the Trello platform, allowing its dissemination and online application. Likewise, the design heuristic implies that to adapt the materials to the context and different users, the materials should have a good visual appearance, clear structure, and cohesion. The lecturers ensured that 'the materials adapt very well (…); the preservice teachers understood the tool quickly and immediately made it their own autonomously'.

The preservice teachers had satisfactory opinions of the TCT material; the average score of all cards was 5.8 ± 0.4. The cards that were most often chosen as useful were the 2.4 Ideation, 4.1 Prototype, 4.2 Presentation, 1.3 Field research, 3.2 Definition of the material, and 1.2 Planning, which in turn scored significantly higher than other cards (without the Bonferroni correction), except 3.2 which did not show any difference (see Table 4). Some cards were often chosen as complex, specifically: 1.4 Analysis of instructional materials to analyse the market, 2.1 Definition of the students using the *Personas* method to empathise, 2.4 Ideation through the brainstorming technique to encourage divergent thinking, or 3.1 Justification of the instructional material to reflect. Some of these cards generated the most questions from preservice teachers. This is understandable because they are activities directly associated with DT, and according to Elwood et al. (2016), the preservice teachers have no previous design experience and do not know basic design patterns. Thus, these results show that teaching DT is not an easy task because the design itself is multidimensional and complex (Brown & Wyatt, 2010; Calavia, Blanco, & Casas, 2021; Dym et al., 2005; Razzouk & Shute, 2012; Teal, 2010). In line with Bain (2005), TCT places students in a position of uncertainty and generates new stimulus, questions, and perspectives that allow them to build useful and applicable knowledge.

5.3. Work process (D3)

The TCT project conducted by the preservice teachers (experimental group) was seen by the lecturers as 'a structured, cohesive, reflective and justified process', especially in comparison with reports made by the control group seen as 'isolated reports' in which

'only the final result is valued (...) without considering the process of how they think, detect the problem, and search for instructional solutions thinking in the students'. This is probably because during TCT process, preservice teachers were encouraged to elaborate design problems in their quest, not start by defining objectives (Kerr, 1981) and solutions, fostering DT through methodologies that can be extrapolated to other projects. In this manner, according to Kleon (2016), it is important to think about the process and not only about the final result. We focused on evaluation and continuous feedback during the design process to help preservice teachers assimilate this concept; making students understand that failure is an essential part of learning (Freeman et al., 2017) and devaluing the final marks that, in line with Sternberg and Lubart (1997), are an important extrinsic motivator. Thus, according to Bain (2005), students are trained properly under the slogan of 'learning by doing and failing'.

Reflections about the design process from the preservice teachers' perspective were collected. In Phase 1, preservice teachers considered it as 'essential, it is the core of the project, since it allows us to detect the needs'. In Phase 2, they highlighted the importance of empathising and using divergent thinking: 'it allowed us to know and analyse the classroom to adapt our instructional material to the context'; 'think about many solutions together (...) until we find the right one'. During Phase 3, they highlighted the importance of justification: 'it allows us to make a useful material and not just attractive'. Finally, in Phase 4, they indicated the redefinition and diffusion importance: 'reflecting on the material allowed us to detect details to improve'; 'it is highly useful to establish a clear and structured guiding thread during the presentation'.

These reflections show that TCT provides the opportunity for preservice teachers to assimilate the design process. This process of assimilation may be related to the 97.8% affirmation of the worth of the TCT process 'I consider the process a beneficial manner to get a good result', even though it is 'a demanding method that has involved much work' (preservice teacher). This is understandable, considering that the process requires the student to be fully active and participating, far from the passive stance adopted in traditional educational methodology (Lee & Erdogan, 2007; McMullan, 2016; Nguyen et al., 2017; Qi, 2017; Zhang & Guo, 2017; Zhao & Meng, 2015).

In addition, according to Table 5, Phase 4 (without Bonferroni correction) had a significantly higher score than Phase 0 and Phase 1. This result is another indicator of how at the beginning, preservice teachers were in a position of uncertainty and how they gradually assimilated and understood the process.

5.4. *Instructional material developed (D3)*

As seen in the Results section, the instructional materials developed with TCT (experimental group) scored significantly higher on the factors of adequacy, usage, and creativity than materials developed by the control group (see Table 6). The lecturers affirmed that it is due to the elaboration of the work process during the project: 'they now work and think more (...); they do not make a material because they have seen it on Pinterest, but there is reasoning and a justification behind (their work)'. Thus, this is mainly because TCT is based on DT, which involves an iterative process (merging divergent and convergent thinking) that promotes creativity (Teal, 2010), and focuses on understanding concepts and providing human-centred solutions (Brown, 2008; Carroll, 2014; Dorst & Cross, 2001; Howard et al., 2008; Mosely et al., 2018; Razzouk & Shute, 2012).

Note that the safety factor did not show significant differences between the experimental and control group, probably because all instructional materials had to satisfy safety criterion to be applied. However, due to its relevance, safety was assessed according to the level of how each team of preservice teachers considered it; at times, some refinements were required.

Due to Covid-19, the preservice teachers did not apply their prototype and did not assess it in the educational environment. Consequently, although TCT provides resources to define the materials entirely, the learning is not complete because, according to Henriksen et al. (2017), applying something real makes students connect thinking with action.

5.5. *Emotions and climate (D4)*

During the project, face-to-face during the first weeks and online afterwards, TCT was used as a communication tool: 'TCT has allowed a better environment among the members (…) as it was a structured and dynamic process, everyone was involved' (lecturer of the subject). Likewise, using Trello as an online platform to collect TCT was crucial: 'Trello allowed us to be connected and to monitor the progress of each group' (lecturer of the subject). Thus, although Trello is not designed for the educational environment, it promotes planning, organisation, and communication between teacher–student and student–student (Delgado et al., 2014; Noguera et al., 2018; Uebe et al., 2019). This reinforces the idea of TCT helps to promote teamwork.

As shown in the Results section, during the TCT experience with the experimental group, there were significant differences between some of the pre-post factors (see Table 7). The preservice teachers felt more entertained than they expected at the beginning; this is important because it is related positively to learning (Schraw & Lehman, 2001). Likewise, they felt less motivated than expected. Probably, this result was conditioned by the Covid-19 situation 'it has been difficult to work on the project in the situation we have experienced'.

Nevertheless, 77.8% of preservice teachers indicated that the TCT methodology was useful in the Covid-19 situation. The majority (82.2%) admitted that the work process in the subject was better than that developed in other subjects. This was justified for three reasons: (1) the continuous work process: 'constant work and not leaving everything to the last minute'; (2) the structure of the methodology: 'greater planning, explanation and monitoring of the project than in the rest of the subjects'; and (3) the feedback provided: 'to be able to contact the lecturers so directly (…) get more explanations and advice than in other projects'. Therefore, designing this process in online format is essential for the digital transformation and remote learning situations such as Covid-19 (Calavia, Blanco, Casas, & Dieste, 2022).

Table 9
Analysis and comparison of similar materials, methods, or studies to TCT found in the literature.

Study	Objective	Sample and context	Assessment method	Findings
Hernández-Leo et al., 2017	A learning design problem-generation tool that consists of 20 stimulus questions to generate deeper thinking about the design problem.	Eight participants with one and five or more years of teaching experience. Workshop of 3 h setting in a postgraduate program.	Survey after the intervention. Documented observation. Review of artefacts produced.	The participants found the tool helpful. There was evidence of the elaboration of the design problems, which suggests that teachers stimulated DT and the problems identification skills.
Henriksen et al., 2017	An online course called 'Learning by Design' (framed by the Stanford model) to address problems of educational practice. The course includes general lectures and workshops.	Twenty-two teachers. Course divided into seven modules of two weeks each as part of a semester of a master's-level teacher education course.	Qualitative assessment of course products, writings, and student-generated discussions.	Educators viewed teaching as a creative DT practice. This study is an initial step toward the creative learning that unfolds in giving educational practitioners DT skills.
Stevenson et al., 2019	A professional learning programme to help teachers working in 'makerspaces', which are spaces that promote constructionist learning with physical materials and digital technologies such as 3D design and 3D printing.	Twenty-seven primary school teachers. Ten-week program that included training, online support and implementation.	Observation. Online questionnaires at beginning, middle and end. Post-project interviews.	Professional development from the DT model and active learning experiences significantly improved teacher confidence to teach in makerspaces.
Elwood et al., 2016	A pilot study that uses a DT approach in a summer program to create a curriculum intervention.	Fifteen in-service teachers of different educational levels in a 5-week program.	Survey pre and post. Semi-structured interview.	The DT approach provides a method for teachers to step back and view the whole picture when designing a curriculum project, avoiding methodically following steps.
Jordan, 2016	A tentative example of a course to support the development of DT by preservice teachers. The course aims to design instructional innovations guided by theories of learning, engagement, and motivation.	A non-defined number of preservice teachers of a 2-years undergraduate elementary education program. An optional 15-week course.	Author discussion and reflections about the experience.	Incorporating the notion of teaching as designing and developing DT capacities in early teacher preparation programs seems promising and worth exploring.
Kali & Ronen-Fuhrmann, 2011	A pedagogic model for teaching educational technology design. Users explore learning through the lenses of design.	Sixty-seven graduate students in education. The model is applied and improved during three successive courses of one semester each.	Survey. Semi-structured interview (16 students). Student artefacts and essays. Reflections written by the teachers.	The model allows structuring the design process, building on repositories of design knowledge, and promoting dialogic learning.
Think-Create-Teach (TCT)	TCT methodology created from an 'x-disciplinary' group and based on DT and an online platform. TCT aims to help preservice teachers formulate their own problems and create their own instructional materials to answer those problems.	Fifty-six preservice teachers and a comparison with a control group of 52 preservice teachers. A compulsory subject for a semester.	Observation, field notes, and periodic internal discussions. Semi-structured interview. Survey. Review of process and artefacts produced.	TCT is adequately integrated into the curriculum and valid for design training. TCT allows preservice teachers to foster their DT, understand the importance of the process, develop soft skills, and design better materials.

5.6. Perceived contributions (D5)

The lecturers reported that one of the key contributions of TCT was 'the near contact to students, the continuous monitoring, the iterative process, and the organisation; other years, there are groups that have not worked so much, and we have not realised it until the final presentation'. Concerning the preservice teachers, the lecturers affirmed that 'I now understand the usefulness of the design in developing materials' and considered it essential to train them in design (Bennett et al., 2017; Elwood et al., 2016; Henriksen et al., 2017; Hernández-Leo et al., 2017; Kirschner, 2015; Mishra & Koehler, 2006; Norton & Hathaway, 2015).

In the pre-survey, the preservice teachers were asked what they expected from the subject. Although some participants used the word 'design' in their responses, most expected to learn existing resources: 'know different materials and resources that we can apply with our future students'. Only two preservice teachers specified 'design' as part of their work. Therefore, according to Hernández-Leo et al. (2017), preservice teachers generally do not understand education as design and do not experience themselves as designers.

In line with Bain (2005), we wanted the preservice teachers to question the mental models documented in the initial perceptions survey. Thus, at the end of the experiment, the preservice teachers were asked about the methodology's contribution to the design of materials. The answers about the contributions can be grouped into three blocks. (1) Planning: 'how important it is to plan since good learning is based on good planning'. (2) Process importance: 'reflect on the aspects to consider during the design of the instructional materials'. (3) The ability to act as designers; 'to be able to design my own materials in the future', 'to learn to design actively and not

theoretically'. Consequently, preservice teachers were helped to achieve 'mind shifts' towards new manners of thinking, in line with Goldman and Zielezinski (2016). This fact may be the major reason they positively valued the usefulness of TCT (5.2 ± 1.1 on a Likert Scale from 0–7).

However, it should be noted that design is multifaceted, messy and complex (Brown & Wyatt, 2010; Calavia, Blanco, & Casas, 2021; Dym et al., 2005; Razzouk & Shute, 2012; Teal, 2010). As mentioned, at first, the preservice teachers saw the process as chaotic, but little by little, they began to understand the process structure: 'at the beginning, we were confused, then we started connecting the process'. In more advanced stages, preservice teachers felt like designers, as was observed in other studies such as Henriksen et al. (2017) or Jordan (2016). For these reasons, TCT provides a strategy to understand the connection of design with learning, a fundamental experience for novices who do not yet have patterns or design experience (Elwood et al., 2016).

Due to these contributions, lecturers affirmed, 'I have no doubt that I would use it again'. The average preservice teachers' answers about using TCT again in the future were high (5.2 ± 1.2 on a Likert Scale from 0–7); however, it is interesting to observe the double standards in some preservice teachers' perceptions. The lowest scores (3 and 4) referred to the fact that 'it is a bit overwhelming' and 'some parts are very laborious'. The highest scores (6 and 7) indicated that 'it is very useful for my future because it ensures a good result since the design process allows reviewing and stepping back'; 'the design of own materials can be much more enriching than offered by certain publishers because they do not know the individual needs'. The lowest scores were related to the effort it required for preservice teachers to learn the TCT approach together with learn to teach itself, as well as the proactive and continuous worked that TCT implies, far from the traditional system requisites; this is a difficult issue, but as the scores show, TCT could contribute to mitigating this phenomenon.

Regarding suggestions for improving the methodology, all preservice teachers affirmed that the methodology includes important aspects to consider when designing instructional materials 'I thought about aspects that I had not considered at the beginning'. This is relevant to their learning, considering their reported uncertainty about other design-based methodologies for creating materials. However, the preservice teachers and the lecturers discussed improvements that are being applied in a new version for the next iteration, which can be grouped into:

- Simplification: 'Summarising the information and simplifying more questions and tips'.
- Join certain cards: 'I do not consider that it needs major improvements, although perhaps join certain cards with similar information (...) some were slightly repetitive'.
- Time: 'I would add more time to dedicate to activities'.
- Communication between teams: 'Maybe do some joint phase or small presentations to know what the rest of the groups are doing'.
- Prototype and practice: 'The only thing I have missed is not being able to apply our instructional material in the classroom with children'.

5.7. *Limitations of study and future work*

Some limitations and further work need to be acknowledged. First, the scope of this study is confined to a specific course of preservice teachers from one university, so the outcomes may not be fully generalisable to different contexts. Thus, future work could explore new applications and assessments of the TCT methodology, which would involve a larger sample size. Each new application of TCT is a new opportunity to include improvements based on identified needs.

Second, qualitative techniques are used in this study; the participants rely on their experience, memories, and expectations. This prevents the study from achieving total objectivity and may bias the research to some extent (Ponterotto, 2005). To minimise this effect and provide greater credibility, we assessed each objective with different methods, and we combined quantitative with qualitative techniques. However, as this study has a mainly quantitative approach, a future study could be conducted, based on the current manuscript, which analyses TCT as a more in-depth qualitative story.

Third, the Covid-19 situation meant that the preservice teachers could not receive some face-to-face workshops and did not test the prototype in the classroom. Thus, the manipulable materials (typical of the design methodologies) had to be virtually replaced; and preservice teachers accomplished a complete definition without applying it in a real context. Nevertheless, Covid-19 has been an invitation to innovate in educational processes; these innovations are essential for the future of education.

Fourth, note that using a facilitator during training is advisable, and this person must be trained in DT. Fifth, even though there is a good facilitator, understanding and developing DT is not a simple task because the design itself is complex, messy, and multifaceted. In addition, preservice teachers are not familiar with this type of training; they are novices and do not have their own patterns. Thus, understanding and developing DT cannot be solved solely with the occasional use of the proposed methodology, but TCT can be an aid to introduce these concepts in preservice teacher training. As a general line of future work, it is necessary that preservice teachers training and educational research delve deeper into supporting educators with new tools and approaches from DT.

6. Conclusions

This paper proposes the Think-Create-Teach (TCT) methodology to train preservice teachers in design thinking to identify needs and design instructional materials to address those needs.

During the methodology development, an x-disciplinary group (formed by three specialists in design and technology and two from

the educational field) adapted DT to an educational environment. As a result, TCT is embodied in a practical manual of 15 guide cards with templates, helping preservice teachers use the DT process from a complete perspective that allows them to step back and connect their knowledge. Both the visual nature of the material and the use of the Trello platform to collect the methodology in digital format are crucial and contribute to the success of the tool even in the Covid-19 situation.

TCT was assessed quantitatively through its application in a compulsory subject of the education degree with preservice teachers (experimental group). In addition, a comparative study was conducted between the work processes and the instructional materials created by the experimental group and the control group. These quantitative results are supported with qualitative methods to understand the reasoning behind. Thus, the results of this assessment showed the successful integration of the TCT methodology in the context. The previous work between disciplines (x-disciplinary group) and the subject based on project-based learning (PjBL) where it was inserted supposed an optimal framework to integrate DT naturally. Likewise, the assessment evidences its validity for the training of preservice teachers in design; they understood the importance of the process, and designed more adequate, usable, and creative materials than the control group using the method from previous years. Thus, this training is a first step that allows preservice teachers to work on their own skills, apply the discipline of design, and address the complex challenges of their future teaching work, such as creating instructional materials.

Consequently, this study reflects the potential of training preservice teachers in DT to include this discipline in education directly. Thus, we contribute to reaffirming (a) the relevant role that the design discipline has in the training of preservice teachers and (b) the need to create new practical solutions to apply and integrate into this training. Research in these directions would enhance the concept of teachers as designers, making them able to identify problems and elaborate solutions in the educational environment.

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CRediT authorship contribution statement

M. Belén Calavia: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Visualization, Writing – original draft. **Teresa Blanco:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – review & editing. **Roberto Casas:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Resources, Project administration, Supervision, Writing – review & editing. **Belén Dieste:** Conceptualization, Data curation, Methodology, Resources, Writing – review & editing.

Declaration of Competing Interest

None.

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