TESIS DE LA UNIVERSIDAD
DE ZARAGOZA

2023

231

María Belén Calavia Ferrández

Aportaciones desde el diseño y la tecnología para el fomento de la creatividad en entornos educativos

Director/es
Casas Nebra, Roberto José
Blanco Bascuas, María Teresa

ISSN 2254-7606

Prensas de la Universidad
Universidad Zaragoza

Servicio de Publicaciones

ISSN 2254-7606

Universidad Zaragoza
1542

Tesis Doctoral

APORTACIONES DESDE EL DISEÑO Y LA TECNOLOGÍA PARA EL FOMENTO DE LA CREATIVIDAD EN ENTORNOS EDUCATIVOS

Autor

María Belén Calavia Ferrández

Director/es

Casas Nebra, Roberto José
Blanco Bascuas, María Teresa

UNIVERSIDAD DE ZARAGOZA
Escuela de Doctorado

Programa de Doctorado en Ingeniería de Diseño y Fabricación

2023

Tesis Doctoral

APORTACIONES DESDE EL DISEÑO Y LA TECNOLOGÍA PARA EL FOMENTO DE LA CREATIVIDAD EN ENTORNOS EDUCATIVOS

Autor

María Belén Calavia Ferrández

Director/es

Roberto Casas Nebra
Teresa Blanco Bascuas

Escuela de Ingeniería y Arquitectura (EINA)
Programa de Doctorado en Ingeniería de Diseño y Fabricación
2023

APORTACIONES DESDE EL DISEÑO Y LA TECNOLOGÍA PARA EL FOMENTO DE LA CREATIVIDAD EN ENTORNOS EDUCATIVOS

M. Belén Calavia Ferrández

2023 Tesis doctoral

Directores:
Dr. Roberto Casas Nebra
Dra. Teresa Blanco Bascuas

Universidad Zaragoza

Tesis doctoral

Autor:

M. Belén Calavia Ferrández

Directores:

Dra. Teresa Blanco Bascuas
Dr. Roberto Casas Nebra

Programa de Doctorado en Ingeniería de Diseño y
Fabricación de la Universidad de Zaragoza.

Zaragoza, marzo de 2023.

Esta tesis doctoral está compuesta por un compendio de seis publicaciones científicas. Los estudios 1, 4 y 5 están indexados en *Journal Citation Reports* (JCR), el estudio 2 ha sido publicado en las actas de un Congreso Internacional, el estudio 3 ha sido publicado como capítulo de un libro y el estudio 6 está indexado en *Scimago Journal & Country Rank* (SJR).

- **Estudio 1:** Calavia, M. B., Blanco, T., & Casas, R. (2021). Fostering creativity as a problem-solving competence through design: Think-Create-Learn, a tool for teachers. *Thinking skills and creativity, 39,* 100761.
  DOI: https://doi.org/10.1016/j.tsc.2020.100761

- **Estudio 2:** Calavia, M.B., Blanco, T., & Casas. R. (2019). Recursos basados en el diseño para fomentar la creatividad en el aula. In *V International Conference on Learning, Innovation and Competitiveness (CINAIC)* (pp. 590-595). Madrid, España.
  DOI: http://dx.doi.org/10.26754/CINAIC.2019.0120

- **Estudio 3:** Calavia, M.B., Blanco, T., & Casas. R. (2019). Formando a personas creativas en la era digital. Evaluación x-disciplinar de una herramienta basada en el diseño. In Foradada, C. & Irala-Hortal, P. (Eds.), *Re_Visiones sobre arte, patrimonio y tecnología en la era digital* (pp. 185-194). Gobierno de Aragón.
  ISBN: 978-84-8380-411-7

- **Estudio 4:** Calavia, M. B., Blanco, T., Casas, R., & Dieste, B. (2022). Making Design Thinking for Education sustainable: Training preservice teachers to address practice challenges. *Thinking skills and creativity,* 101199.
  DOI: https://doi.org/10.1016/j.tsc.2022.101199

- **Estudio 5:** Calavia, M. B., Blanco, T., Casas, R., & Dieste, B. (2022). Improving Design Project Management in Remote Learning. *Sustainability, 14*(17), 11025.
  DOI: https://doi.org/10.3390/su141711025

- **Estudio 6:** Calavia, M. B., Blanco, T., Serrano, A., Biedermann, A., & Casas, R. (2022). Think-Sketch-Create: Improving Creative Expression Through Sketching. In Gerbino, S., Lanzotti, A., Martorelli, M., Mirálbes Buil, R., Rizzi, C., Roucoules, L. (Eds.), *Advances on Mechanics, Design Engineering and Manufacturing IV. JCM 2022. Lecture Notes in Mechanical Engineering* (pp. 1585-1597). Springer, Cham.
  DOI: https://doi.org/10.1007/978-3-031-15928-2_138

Agradecimientos

Mi pequeña montaña rusa (Figura 1), este es el mejor calificativo para describir el proceso de mi tesis. A veces, me he sentido enorme, y otras, pequeña y de cristal. Algunos días tenía claro lo que quería, y otros, una curva me hacía reflexionar sobre si realmente hacía lo correcto.

Lo bonito es que al final del trayecto puedo asegurar que la tesis me ha dado mucho, y que comprar los tiques para vivir este viaje fue lo correcto. Más allá de los conocimientos y las competencias específicas, me quedo, al igual que en mis estudios, con mi aprendizaje transversal: elegir lo que me late, con las dos vertientes de no correr durante el trayecto, pero tampoco parar. Y así, con este aprendizaje, es como quiero seguir afrontando todo lo nuevo que venga.

Fig 1. Mi montaña rusa creativa.

Esta tesis no habría sido posible sin todas personas que me han acompañado durante el viaje. Todos los vagones de mi pequeña montaña rusa han estado completos por pasajeros, a los que quiero darles las gracias por contribuir con su energía: potencial y cinética.

En primer lugar, agradecer a mis directores, que han sido "ascendientes" para mí. Sin vosotros no podría haber escrito esta tesis. Teresa, gracias por tu confianza, dedicación y enseñanza sobre la importancia del detalle. Roberto, gracias por tu apoyo, saber estar y enseñanza sobre que lo resolutivo siempre es bien. También a mis compañeros de Howlab, a los que ya considero buenos amigos. Gracias por estar siempre a golpe de café en la Sala Google y escuchar mis inquietudes, aunque sean distantes a vuestro trabajo. Por lo que sea, espero celebrar este final de tesis con un cachopo de rechupete.

No puedo olvidarme de mis compañeras de docencia que han dedicado tiempo en formarme y de las que tanto he aprendido, gracias por acogerme y darme libertad para hacer mis "cosas". De igual modo, gracias al alumnado que valoró positivamente mi formación, vuestros aplausos son el mejor aliciente para continuar. Aprovecho también para valorar al buen profesorado que me ha formado durante estos años, por ser fuente de inspiración; y al no tan bueno, por esclarecerme el camino. También agradecer a las personas evaluadoras internacionales la revisión de mis trabajos, a cada miembro del tribunal por ser epílogo de este viaje, y al Gobierno de Aragón y la Universidad de Zaragoza por haberme dado la posibilidad de cumplir esta ilusión en tierra noble.

Y sin duda, y en especial, a mi familia. A mis padres, que creo que a día de hoy siguen sin tener muy claro que he hecho, gracias por confiar en cada una de mis decisiones y ser un referente para mí. Papá, el ejemplo más claro de trabajo duro y constancia, y mamá, el ejemplo más claro de amor y humanidad. Gracias por darme amparo en vuestra burbuja, y por absolutamente todo.

A mi hermana, por cuidarme desde siempre, ser mitad y restar importancia a cada uno de mis agobios. Junto con mi estupendo cuñado, gracias por haberme dado el mejor regalo en este viaje: mi ahijado. Siempre risueño, ha sabido sacarme las sonrisas más difíciles. Gracias al resto de mi familia formidable, con mención de honor a mi abuela, mi templo de fortaleza; y también a las nuevas incorporaciones políticas, siempre sois energía.

Agradecer también a mis amigas, en especial a las mujeres de Nico, gracias por crecer juntas, sumar siempre y estar orgullosas de mí, como yo lo estoy de vosotras. No me olvido de Primas, Catalán, PowerPoint, Niques, Panas, Oficial y Ziris, gracias por ser siempre aire fresco.

Y finalmente a ti, Javier. La persona que ha sostenido todas las curvas, subidas y bajadas de mi montaña rusa; siempre sentado en mi vagón, con un brazo sobre mis hombros para cuidarme. Solo puedo darte las gracias por estar siempre, ser el mejor compañero de montaña rusa y trazar conmigo los planes hacia el infinito.

Resumen

En un mundo en constante cambio en el que el futuro de la sociedad es incierto, es esencial formar a los futuros profesionales en competencias transversales como la creatividad, entendida como resolución de problemas. Guilford (1950) preguntó en su discurso en la Asociación Americana de Psicología por qué las escuelas no producían personas más creativas. Es cierto que desde entonces el interés por la creatividad ha aumentado y se han conseguido grandes avances hacia un modelo educativo basado en el aprendizaje por competencias; sin embargo, hoy por hoy, todavía es difícil responder a esta pregunta, ya que en la práctica continúa siendo difícil de abordar. Ante esta situación, se identifica la necesidad de seguir avanzando en la búsqueda de soluciones y formas de aprendizaje diferentes a la copia, la memoria o la reproducción, para promover competencias transversales como la creatividad.

En este contexto de trayectorias educativas cambiantes, una de las áreas de conocimiento que puede tener una influencia positiva en esta tarea es el campo del diseño y el *Design Thinking* en su sentido más amplio; que proporciona una mente más abierta y crea un marco eficaz para promover la creatividad como elemento transversal. Asimismo, el terreno de las Tecnologías de la Información y Comunicación (TIC) y el *sketching* ofrecen posibilidades para compartir ideas y contenido, así como oportunidades para una educación creativa. Por tanto, existe la necesidad de apoyar al profesorado con soluciones prácticas desde el punto de vista de estas disciplinas que les ayuden en su labor docente como entrenadores, proveedores de recursos y diseñadores.

Para ello, el trabajo de esta tesis se enmarca bajo una estrategia de investigación basada en ciclos de diseño (desarrollo de soluciones prácticas) y evaluación (testeo en entornos reales). Este proceso se materializa a través de un equipo de especialistas de los ámbitos del diseño, la tecnología y la educación que trabajan conjuntamente desde un enfoque científico. Como punto de partida, se establece un marco teórico basado en 15 factores clave de la creatividad a tener en cuenta a la hora de diseñar un nuevo recurso para el aula: incorporación al currículo, practicidad, novedad, clima, estimulación, análisis, cooperación, motivación intrínseca, participación, flexibilidad, incertidumbre, tiempo de reflexión, divergencia, autoevaluación y redefinición.

En base a esto, esta tesis presenta cuatro nuevas estrategias apoyadas en materiales prácticos y flexibles. Por un lado, dos metodologías para fomentar competencias transversales como la creatividad en los entornos educativos: *Think-Create-Learn* (TCL) para ayudar al profesorado a aplicar el *Design Thinking* en el aula; y *Think-Create-Teach* (TCT) para capacitar al futuro personal docente para que sea capaz de formular problemas y crear sus propios materiales didácticos. Por otro lado, dos herramientas de aprendizaje para integrar de manera natural las metodologías desarrolladas: el tablero online *DT-based board* para mejorar la implementación y gestión de proyectos de diseño a distancia; y *Think-Sketch-Create* (TSC) para ayudar al alumnado a expresar sus pensamientos e ideas a través del dibujo.

El diseño, desarrollo y validación de estas estrategias se aborda a través de seis estudios de investigación, en los que se utilizan métodos mixtos (cualitativos y

cuantitativos) para su evaluación en entornos reales con profesorado y alumnado de diferentes especialidades, elegidos intencionalmente de acuerdo con los objetivos de cada estudio. Los resultados de estos estudios demostraron la integración positiva de las nuevas estrategias en las líneas curriculares vigentes, y su validez para desarrollar competencias transversales dentro de los entornos educativos de acuerdo con los 15 factores de la creatividad propuestos. A través de su aplicación, profesorado y alumnado desarrollaron nuevos modos de pensar para cuestionarse, plantear retos y generar soluciones innovadoras. Se demostró que estas nuevas estrategias favorecen un clima adecuado para experimentar sin miedo al fracaso, potencian el trabajo en equipo, combinan pensamiento convergente y divergente, promueven la importancia del proceso más que del resultado final, así como la reflexión, retroalimentación y redefinición.

El trabajo aquí reunido aporta nueva teoría, avanza en el conocimiento y reafirma cómo el *Design Thinking* y la tecnología son una oportunidad para crear nuevas soluciones prácticas que fomenten competencias transversales en los entornos educativos. La investigación en estas líneas es un paso para ayudar al profesorado a responder a la educación cambiante de hoy, mejorando su calidad para las generaciones futuras hacia una sociedad sostenible.

Abstract

In a constantly changing world where the future of society is uncertain, it is essential to train future professionals in transversal competencies such as creativity, understood as problem solving. Guilford (1950) asked in his lecture at the American Psychological Association why schools did not produce more creative people. It is true that since that time, interest in creativity has increased and great progress has been made towards an educational model based on competence-based learning; however, today, it is still difficult to answer this question, since in practice it continues to be difficult to address. In this situation, there is a need for further progress in the search for learning solutions other than copying, memory or reproduction, in order to promote transversal competences such as creativity.

In this context of changing educational trajectories, one of the knowledge areas that can have a positive influence on this task is the field of design and Design Thinking in its broadest sense; it provides a more open mind and creates an effective framework for promoting creativity in a transversal manner. Furthermore, the field of Information and Communication Technologies (ICT) and sketching offer possibilities for sharing ideas and content, as well as opportunities for creative education. Thus, there is a need to support teachers with practical solutions from the perspective of these disciplines to assist them in their teaching work as trainers, resource providers and designers.

To face these needs, this thesis adopts a research strategy based on cycles of design (development of practical solutions) and evaluation (testing in real environments). This process is materialised through a team of specialists from the fields of design, technology and education who work together from a scientific approach. As a starting point, a theoretical framework is established based on 15 key creativity factors to be considered when designing a new resource for the classroom: incorporation, practicality, novel, atmosphere, stimulation, analysis, cooperation, intrinsic motivation, participation, flexibility, uncertainty, time, divergence, self-evaluation, and redefinition.

On this basis, this thesis presents four new strategies supported by practical and flexible materials. On the one hand, two methodologies to foster transversal competences such as creativity in educational environments: Think-Create-Learn (TCL) to support teachers to apply Design Thinking in the classroom; and Think-Create-Teach (TCT) to train preservice teachers to be able to formulate problems and create their own didactic materials. On the other hand, two learning tools to naturally integrate the developed methodologies: the online DT-based board to improve the implementation and management of remote design projects; and Think-Sketch-Create (TSC) to empower students to express their thoughts and ideas through drawing.

The design, development and validation of these strategies is addressed through six research studies, using mixed methods (qualitative and quantitative) for evaluation

in real environments with teachers and students from different specialties, intentionally chosen according to the objectives of each study. The results of these studies demonstrated the positive integration of the new strategies into the curricular lines, and their validity in developing transversal competences within educational environments according to the 15 creativity factors proposed. Through their application, teachers and students developed new patterns of thinking in order to question themselves, pose challenges and generate innovative solutions. These new strategies were shown to foster a favourable climate for experimenting without fear of failure, enhance teamwork, combine convergent and divergent thinking, promote the importance of the process rather than the results, as well as reflection, feedback, and redefinition.

The presented work provides new theory, advances knowledge, and reaffirms how Design Thinking and technology are an opportunity to create new practical solutions that foster transversal competences in educational environments. Research along these lines advances in supporting teachers to address today's changing education, improving the quality of education for future generations towards a sustainable society.

Tabla de contenido

1. Introducción

En esta sección se presenta la justificación del tema de tesis junto con las necesidades derivadas de la revisión bibliográfica (1.1), los objetivos de investigación (1.2), el contexto en el que se desarrolla la tesis (1.3), y la metodología seguida para su desarrollo (1.4).

1.1. Revisión bibliográfica

El objetivo de este capítulo es reflexionar sobre el tema principal de la tesis que se presenta: el fomento de la creatividad, entendida como resolución de problemas, en los entornos educativos.

Durante los años de formación, la mayoría del alumnado pasa horas trabajando el pensamiento convergente; la forma en la que normalmente se les presenta la información, así como la forma de examinarles, hace que aprendan a tomar decisiones concretas (de Vries & Lubart, 2019; Hensley, 2018). Algunos ejemplos directos de este tipo de formación son: un problema de matemáticas con un único procedimiento, una frase de sintaxis o un examen tipo test en el que se elige la única respuesta correcta. Pero ¿qué sucede con el pensamiento divergente o lateral? ¿con la exploración de posibles soluciones? ¿con las competencias transversales como la creatividad? ¿con las necesidades e intereses del alumnado?

Como veremos a lo largo de este capítulo, en un mundo en constante cambio y ante un futuro incierto, se precisa de equipos con competencias transversales (Clarke, 2018; Moore & Morton, 2017; Tulsi & Poonia, 2015) que, además de resolver tareas directas, sean capaces de no ir de "A - B" en línea recta buscando la respuesta correcta, sino de cambiar la dirección y pivotar hacia el descubrimiento de nuevas posibles perspectivas. Así, de acuerdo con Guilford (1967b) ambos modos de pensamiento (convergente y divergente) son necesarios. Más allá de buscar y promover respuestas, es necesario que los entornos educativos susciten al alumnado a plantear sus propias preguntas sin miedo al fracaso, explorando y descubriendo problemas o necesidades que les lleven a combinar los conocimientos aprendidos para dar respuestas. En consecuencia, se trata de invertir el paradigma y hacer que el interés de las escuelas no se enfoque en enseñar, sino en que el alumnado aprenda (Bain, 2005).

Asimismo, en la era digital actual en la que nos encontramos, el alumnado tiene acceso directo con un solo clic a todo el contenido. Existen infinidad de vídeos explicativos, webs con multitud de recursos, buscadores de documentos académicos, blogs educativos, libros, etc. Por tanto, la labor del profesorado no se puede limitar únicamente a transmitir conocimiento al estudiante como en la educación del siglo XVIII, heredada en algunas situaciones; sino que también debe apoyar el desarrollo de sus habilidades y adoptar nuevos roles como entrenador, proveedor de recursos y diseñador. De hecho, diferentes autores abogan por considerar a las personas docentes como diseñadoras (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), ya que en su día a día enfrentan y resuelven desafíos complejos como, entre otros: el diseño de lecciones y planes de estudio, el desarrollo de materiales didácticos y metodologías, la motivación del alumnado, el clima escolar o las relaciones (Henriksen et al., 2017).

El desafío global de educar para la era actual lleva años en continua mejora y reforma. La nueva Ley Orgánica 3/2020, de 29 de diciembre, por la que se modifica la Ley Orgánica 2/2006, de 3 de mayo, de Educación (LOMLOE), de aplicación en España que está entrando en vigor de forma progresiva, se hace eco de la importancia de formar en competencias y trabajar por proyectos para conseguir una ciudadanía comprometida con el cambio, así como de otorgar un mayor protagonismo al profesorado, siendo promotor activo del cambio y epicentro de todas las innovaciones metodológicas.

A nivel de investigación, Europa, España y la comunidad autónoma de Aragón también apuestan por investigar hacia una educación de calidad. En el pasado más próximo, el Horizonte 2020 y la Estrategia Aragonesa de Investigación e Innovación para una Especialización Inteligente (RIS3) identificaron como clave la necesidad de desarrollar métodos educativos innovadores centrados en el alumnado, así como la importancia de ampliar las oportunidades de aprendizaje de la ciencia, aumentando la conciencia sobre su importancia y atrayendo a la gente joven a carreras científicas. Tal y como recogen dichos documentos, es necesaria la conexión entre sistema educativo y demandas industriales ya que, en todos los sectores, se requieren personas trabajadoras con competencias transversales.

Así, el impulso de competencias transversales como la creatividad en el alumnado desde las primeras etapas de la educación ayuda en la capacidad de explorar y detectar necesidades, resolver problemas, y tomar decisiones con iniciativa y razonamiento crítico. Asimismo, en las líneas actuales de Horizonte Europa, la creatividad aparece como un desafío mundial en "Cultura, creatividad y sociedad inclusiva", siendo un reto de gran envergadura que contribuye a los Objetivos de Desarrollo Sostenible (ODS). Concretamente, con el compromiso del ODS 4 "educación de calidad", cuya meta 4.4 sigue la línea de "(…) aumentar considerablemente el número de jóvenes y adultos que tienen las competencias necesarias (…)".

En este contexto de trayectorias educativas cambiantes, y de acuerdo con las estrategias descritas, el proyecto de tesis que se presenta a continuación pretende contribuir en el modelo educativo basado en el aprendizaje por competencias. Para ello, a través del *Design Thinking* y la tecnología se proponen nuevas estrategias para la formación de docentes y estudiantes en habilidades transversales como la creatividad, haciendo que desarrollen este potencial y puedan aplicarlo en cualquier ámbito o disciplina, ya que, en todos los sectores es necesario detectar, enfrentar y resolver desafíos complejos. Todo ello con un enfoque enmarcado bajo el siguiente paradigma:

"Dale un pez a un hombre y comerá hoy.

Enséñale a pescar y comerá el resto de su vida".

Proverbio chino.

Un paso más allá de este sabio proverbio, esta tesis se fundamenta en que el ámbito educativo haga que el alumnado "aprenda a pescar", capacitándole para identificar necesidades y crear sus propias "cañas de pescar" de acuerdo con el contexto de sus "ríos" o "mares".

1.1.1. Marco educativo

Tal y como sucede desde el inicio de nuestra especie, el cambio nos rodea y la sociedad evoluciona constantemente, lo cual genera importantes desafíos y repercusiones en todas las áreas de la sociedad (Gisbert & Esteve, 2016) incluida la educación (Luka, 2014; Sancho-Gil & Hernández-Hernández, 2018). En respuesta a estos desafíos urgentes como son la utilización no sostenible de los recursos, el cambio climático o la desigualdad, la Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura (UNESCO) plantea la educación para el desarrollo sostenible.

La educación para el desarrollo sostenible implica un aprendizaje dirigido a desarrollar conocimientos y capacidades transversales para enfrentar y resolver los problemas de nuestra sociedad, asegurando el bienestar de las generaciones futuras (Nousheen et al., 2020; Tejedor et al., 2022). Esto conlleva acercar al alumnado a los ideales de la sostenibilidad en sus dimensiones social, económica y ambiental. Los entornos educativos deben empoderar al alumnado en la adquisición de competencias hacia la sostenibilidad para que se conviertan en agentes de cambio y sean capaces de adaptarse a lo largo de su vida a un mundo en evolución (Tejedor et al., 2022); asumiendo que la sostenibilidad no se anticipa como un resultado definitivo, sino como una dirección global que considera largos periodos de tiempo (Buhl et al., 2019).

Del mismo modo, en los distintos sectores de trabajo se precisa cada vez más de equipos con capacidades transversales (Clarke, 2018; Moore & Morton, 2017; Tulsi & Poonia, 2015), lo que requiere formar a los futuros profesionales de manera diferente (Achtenhagen, 2001; Blanco 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). Así, la metodología tradicional basada principalmente en la instrucción docente, el aprendizaje pasivo a través de la copia, la memoria o la reproducción (Lee & Erdogan, 2007; McMullan, 2016; Nguyen et al., 2017; Qi, 2017; Zhang & Guo, 2017; Zhao & Meng, 2015), y la evaluación mediante pruebas estandarizadas (Carroll et al., 2010), resulta a menudo ineficaz para satisfacer las nuevas necesidades educativas y sociales (Luka, 2014).

Bajo este contexto, la educación se encuentra inmersa en un proceso de cambio, en el que la innovación tiene un papel fundamental. Innovar en educación implica pensar, diseñar, planificar y evaluar proyectos que resuelvan problemas, que respondan tanto a demandas internas como a demandas externas (Pérez & Tejedor, 2016). En los últimos años, los procesos de innovación fundamentados en el modelo educativo basado en el aprendizaje por competencias han venido a modificar la metodología tradicional (Blanco et al., 2017b; Hoogveld et al., 2005; Martínez et al., 2019). Este enfoque incluye capacitar al alumnado en competencias transversales o *soft skills* como la comunicación, el trabajo en equipo, el pensamiento crítico o la creatividad (Carroll et al., 2010; Razzouk & Shute, 2012). El concepto de competencia se entiende como "la combinación dinámica de conocimiento, entendimiento, capacidades y habilidades enfocadas a preparar a los estudiantes para su futuro papel en la sociedad, en términos de empleabilidad y ciudadanía" (Blanco, 2016, p.250). Por tanto, no se trata de sustituir los contenidos por competencias, sino que ambos conceptos se deben nutrir e integrar conjuntamente.

En este sentido, la educación avanza desde un paradigma conductista (aprendizaje como adquisición de respuestas) hacia un paradigma constructivista (aprendizaje como construcción de significados) (Serrano & Pons, 2011). Desde una perspectiva pedagógica, existen diferentes teorías para entender el constructivismo, pero todas ellas comparten que el conocimiento es un proceso de construcción del propio sujeto. La tendencia en educación es integrar varias teorías a fin de lograr un marco global (Serrano & Pons, 2011). Así, se combinan las posiciones del constructivismo cognitivo, basadas en la teoría de Piaget, sobre construir el conocimiento desde la interacción con el medio; con los principios del constructivismo de corte social, basados en Vygotsky, donde el factor social es determinante en la construcción del conocimiento (Castellaro & Peralta, 2020). En definitiva, un enfoque que integra una perspectiva social basada en los procesos colectivos y compartidos en el aula, y una perspectiva psicológica basada en la actividad individual de cada alumno y alumna mientras participa en los procesos compartidos (Serrano & Pons, 2011).

Este enfoque es clave para el modelo educativo basado en el aprendizaje por competencias por dos razones: en primer lugar, “porque los profesores ya no imparten conocimientos a los alumnos”, sino que les brindan herramientas para ayudarles a construir su propio conocimiento, lejos de asumir al estudiante como un ser pasivo que no aporta a la situación de aprendizaje; y, en segundo lugar, “porque el enfoque constructivista de la educación acentúa la importancia del contexto para un eficaz y eficiente desarrollo de los procesos de aprendizaje” (Serrano & Pons, 2011, p.18).

Todo ello ha implicado que, desde finales del siglo pasado, el profesorado no sólo utilice métodos expositivos, sino que también trabaje con métodos participativos basados en el enfoque constructivista para capacitar al alumnado en competencias transversales (Velázquez et al., 2020). Guillén-Gámez et al. (2020) aplican el Aprendizaje Cooperativo para el desarrollo de competencias del futuro personal docente. Duran y Dökme (2016) indican los efectos significativos de introducir actividades de Aprendizaje Basado en Investigación para promover las competencias de pensamiento crítico. Caniglia et al. (2016) presentan y demuestran cómo el Aprendizaje Basado en la Experiencia en los cursos introductorios de nivel universitario fomenta el desarrollo de habilidades en sostenibilidad. Seitamaa-Hakkarainen y Hakkarainen (2017) destacan el creciente interés en experiencias de Aprender haciendo para cultivar nuevas formas de pensar y actuar. Dag y Durdu (2017) implementan el Aprendizaje Basado en Proyectos con futuro personal docente, quienes reportaron mejores habilidades de resolución de problemas y colaboración.

En estas metodologías activas, el alumnado se convierte en el centro del proceso educativo (Moya, 2017), permitiendo al estudiante ser protagonista de su propio aprendizaje y desarrollar sus *soft skills* (Starkey, 2019). Sin embargo, a nivel práctico, alcanzar este modelo educativo basado en el aprendizaje por competencias es un desafío complejo para el profesorado (Blanco et al., 2017b; Wilhelm et al., 2002). Dado que las *soft skills* se consideran asuntos transversales, no se encuentran a menudo cursos centrados específicamente en su desarrollo (Blanco et al., 2017a; Fernandes et al., 2012).

Entre las competencias transversales, esta tesis destaca la creatividad; entendida como capacidad de conectar los conocimientos aprendidos para resolver problemas y crear cosas nuevas (Kleiman, 2008). La creatividad permite a la sociedad avanzar y mirar más allá de los caminos establecidos, respondiendo a un mundo cambiante y aumentando la calidad de vida de las personas (De Bono & Castillo, 1994; Hernández-Torrano & Ibrayeva, 2020; Spendlove, 2008). Nuestro punto de partida es entender la creatividad como capacidad de resolución de problemas (Fasko, 2001; Feldhusen & Treffinger, 1985; Guilford, 1967a; Khalid et al., 2020), que requiere de un proceso cognitivo alejado del mito de la suerte o chispa divina (Howard et al., 2008), y que no se trata de una capacidad limitada a algunas personas, sino que, en mayor o menor medida, está presente en todos los seres humanos (Collard & Looney, 2014; Guilford, 1950).

Despertar, estimular y desarrollar este potencial requiere formación en un entorno favorable (Burkus, 2013; López, 2008). Indudablemente, los entornos educativos son clave en este propósito: el alumnado pasa mucho tiempo allí y llega a todo tipo de clases sociales (Chan & Yuen, 2014; Davies et al., 2013; Shaheen, 2010). De hecho, de acuerdo con Daly et al. (2014) o Fasko (2001), la creatividad debería estar incrustada transversalmente dentro de todo el currículo de los programas educativos; estando presente en cuatro pilares (Figura 2): docente, estudiante, entorno y recursos metodológicos (López, 2008).

Fig 2. La creatividad en todo el sistema.

Hace décadas, Guilford (1950) se preguntaba ¿por qué las escuelas no producen personas más creativas? Es visible que desde entonces se han conseguido grandes avances y el interés por la creatividad dentro de la educación ha aumentado. De hecho, hace unos años comenzó a extenderse por todo el mundo un cambio en la política educativa con el objetivo de combinar la creatividad y el conocimiento como motor de la mejora escolar (Burnard, 2006; Collard & Looney, 2014; Dickhut, 2003). Así, la creatividad se ha convertido en uno de los focos curriculares y pedagógicos (Wilson, 2005) en varios niveles educativos, desde los primeros años hasta la educación primaria para la mayoría de los países y hasta la educación superior, para algunos de ellos (Shaheen, 2010). De hecho, se considera una de las habilidades de pensamiento más importantes del siglo XXI (Ahmadi et al., 2019; Collard & Looney, 2014; Guo & Woulfin, 2016; Henriksen et al., 2016; Mishra & Mehta, 2017; Nakano & Wechsler, 2018).

Desafortunadamente, en la práctica continúa siendo difícil de lograr y a menudo se reduce como un área separada de otros objetivos educativos (Spendlove, 2008). Así, a pesar de lo antedicho, en general, los entornos educativos no se centran en "generar" individuos creativos (Henriksen et al., 2017). Esto se debe a ciertas barreras de diversa índole, entre las que destacar:

- Uno de los mayores problemas es el fuerte predominio de la metodología tradicional que todavía prevalece en muchas ocasiones en la educación formal. Esta metodología se basa en entender al alumnado como una pizarra en blanco sobre la que grabar información; en el uso de conferencias y aprendizaje pasivo, donde el alumnado escucha o ve cómo el instructor resuelve problemas; y en los libros de texto (Lee & Erdogan, 2007; McMullan, 2016; Nguyen et al., 2017; Qi, 2017; Zhang & Guo, 2017; Zhao & Meng, 2015).
- Otro factor importante es que, como área de conocimiento, la creatividad es una actividad polifacética, relativamente nueva y desconocida. Como declara López (2008, p.61) "enseñar creatividad es quizás una de las metas más complicadas en el sistema educativo. Porque busca fomentar lo divergente en un entorno convergente; lo indefinido en un sistema que busca transmitir lo definido conocido".
- Asimismo, el término "creatividad" es frecuentemente utilizado de manera incorrecta; creatividad e imaginación se usan indistintamente (Craft, 2002), y la creatividad se vincula, por defecto, con las artes o el ocio (Henriksen et al., 2017; Seltzer & Bentley, 1999). Además, el término está rodeado de mitos arraigados (Burkus, 2013; Cropley, 2016; Cropley, 2018; MacLaren, 2012) ajenos a la idea de la creatividad como proceso.

Así, cada vez más, la educación aboga por un modelo educativo basado en el aprendizaje por competencias. No obstante, es notable que a nivel práctico continúa siendo difícil de lograr, y que existe la necesidad de seguir aportando en la búsqueda de soluciones sostenibles y formas de aprendizaje distintas a la copia, la memoria o la reproducción, que fomenten competencias transversales como la creatividad, hacia una sociedad sostenible.

1.1.2. Diseño y *Design Thinking*

Teniendo en cuenta estos antecedentes, es clara la necesidad de soluciones prácticas que ayuden al profesorado a fomentar competencias transversales como la creatividad en las aulas. Una de las áreas de conocimiento que puede influir muy positivamente en este cometido es el campo del diseño y el *Design Thinking* en su sentido más amplio. El *Design Thinking* consiste en la formulación y resolución de problemas complejos a través de un proceso creativo centrado en el ser humano, el cual implica a las personas como parte activa desde el principio (Brown, 2008; Carroll, 2014; Dorst & Cross, 2001; Howard et al., 2008; Mosely et al., 2018; Razzouk & Shute, 2012). El *Design Thinking* se considera adecuado para abordar desafíos caracterizados por un alto nivel de incertidumbre, como la mayoría de los problemas relacionados con la sostenibilidad (Victorino et al., 2022). Por tanto, el *Design Thinking* proporciona un marco para la innovación, lo que implica la creación de nuevos (o mejorados) productos, servicios, procesos o prácticas que persiguen beneficios sociales o medioambientales (Buhl et al., 2019).

El concepto actual de *Design Thinking* se deriva de las teorías de diseño tradicionales aplicadas en la práctica del diseño industrial (Razzouk & Shute, 2012). Se han recopilado diferentes metodologías bajo el *Design Thinking* (Brown & Wyatt, 2010; Design Council, 2021; Stanford University Institute of Design, 2021), que, tal y como se observa en la Figura 3, generalmente constan de tres estados principales: inspiración, ideación e implementación (Brown & Wyatt, 2010). La inspiración consiste en explorar e identificar el problema o desafío a través de la investigación y la observación. La ideación es un proceso creativo para abordar el reto detectado. La implementación convierte las ideas en acciones. En todas estas fases, existen dos tipos principales de pensamiento (Figura 3): el convergente, que se mueve en una dirección y busca una determinada respuesta o solución, y el divergente, que se mueve en varias direcciones y plantea nuevas estrategias para abordar las situaciones (Dym et al., 2005). Así, el *Design Thinking* logra un equilibrio entre el pensamiento convergente y divergente y fomenta ambas perspectivas, lo cual es esencial para desarrollar la habilidad transversal del pensamiento creativo (Elwood et al., 2016; Gu et al., 2019; Hadar & Tirosh, 2019).

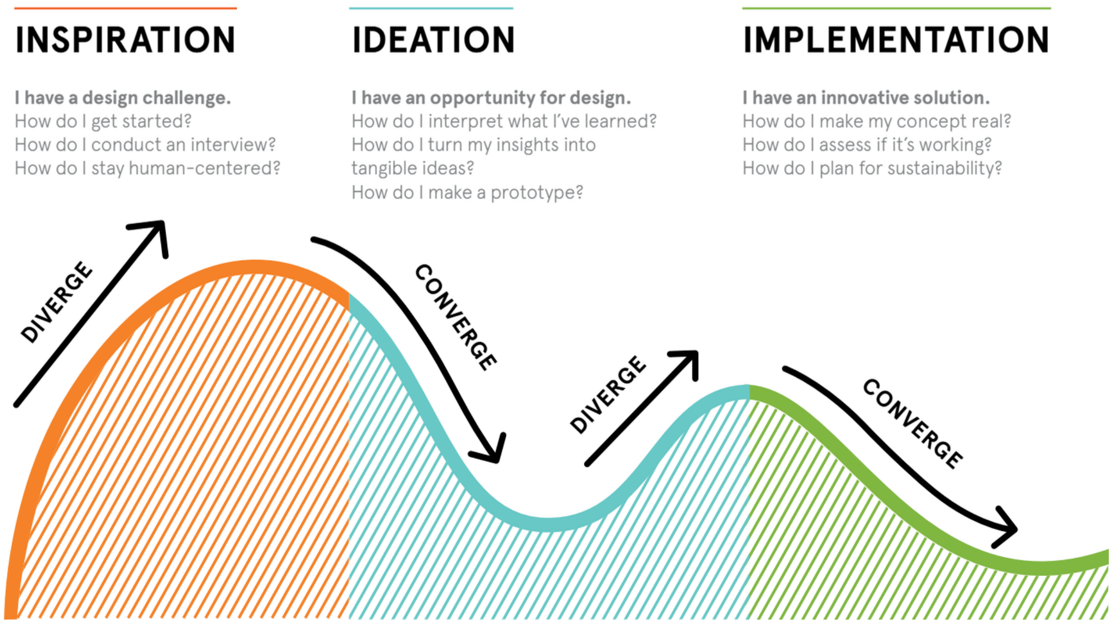


Fig 3. Modelo de Diseño Centrado en las Personas (IDEO, 2015).

Por tanto, se puede afirmar que creatividad y diseño están íntimamente relacionados, y muchos autores reconocen el *Design Thinking*, per se, como un proceso creativo (Elwood et al., 2016; Henriksen et al., 2017; Hernández-Leo et al., 2017; Jordan, 2016; Koehler & Mishra, 2005). El *Design Thinking* es un proceso iterativo que reformula repetidamente un problema para encontrar su núcleo y luego analiza posibles soluciones para encontrar la más favorable, lo que permite la creación de puentes creativos entre problemas y soluciones (Cross, 2011; Dorst & Cross, 2001) (Figura 4).

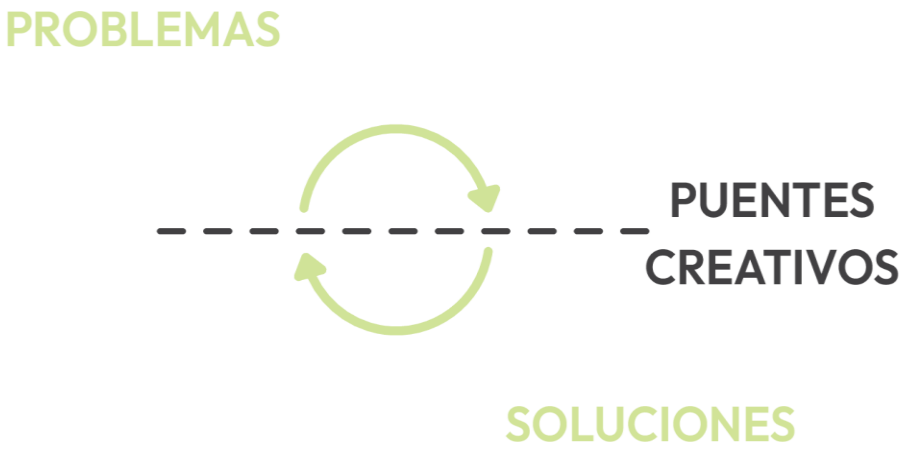


Fig 4. Conexión entre Design Thinking y creatividad.

En esta línea, durante la presente tesis se afronta la necesidad de fomentar competencias transversales como la creatividad en los entornos educativos, a partir de las oportunidades que ofrece la perspectiva del *Design Thinking.*

1.1.3. *Design Thinking* en educación

Como afirma Blanco (2016, p.19), "El enfoque desde el diseño representa una ventaja diferencial, tanto por la conceptualización y el modo de aproximación al problema, como por la eficiencia, asequibilidad y adaptabilidad de sus herramientas". Esto ha implicado que el *Design Thinking* se aplique activamente en diferentes campos fuera del diseño (Blanco, 2016; Dorst, 2010; Mosely et al., 2018), tan diversos como la ingeniería, los entornos empresariales, la educación o la medicina (Lindberg et al., 2011; Lor, 2017; Marín et al., 2019; Martin & Martin, 2009; Razzouk & Shute, 2012).

En el ámbito que nos ocupa la presente tesis, el campo de la educación, el *Design Thinking* proporciona una mente más abierta al alumnado, crea un marco eficaz para promover la creatividad como elemento transversal (Mosely et al., 2018; Thorsteinsson & Page, 2017) y mejora las competencias transversales (Goldman & Zielezinski, 2016; Howard et al., 2008; Lor, 2017; Luka, 2014; Mosely et al., 2018; Naghshbandi, 2020; Wright & Wrigley, 2017) como la colaboración, la resolución de problemas o la innovación, que según Brundiers et al. (2021) son competencias clave hacia una educación para el desarrollo sostenible.

Estos beneficios han hecho que la aplicación del *Design Thinking* en la educación sea cada vez más popular en todos los niveles, desde los primeros años hasta la universidad. En el primer grado de Educación Primaria, Coleman (2016) presenta un proyecto de investigación para diseñar una casa mejor para los tres cerditos. Grammenos y Antona (2018) describen un curso intensivo, interactivo y participativo con estudiantes de quinto y sexto, a quienes denominan *future designers*, que tiene como objetivo introducirles en conceptos y prácticas de creatividad, diseño y *Design Thinking*. Carrol et al. (2010) analizan la experiencia de aprendizaje de estudiantes de secundaria al aplicar el proceso de *Design Thinking*. Del mismo modo, Scheer et al. (2012) evalúan y analizan el *Design Thinking* como método de enseñanza para estudiantes de secundaria. Asimismo, a nivel universitario, el *Design Thinking* se ha aplicado en diversos campos del conocimiento como las especialidades de ingeniería (Blanco et al., 2017a; McKilligan et al., 2017), y docencia (Jordan, 2016).

No obstante, a pesar de que diferentes autores abogan por que el profesorado aplique el *Design Thinking* en sus aulas (Brown, 2008; Carroll et al., 2010; Lin et al., 2020; Lor, 2017; Razzouk & Shute, 2012; Retna, 2016), la formación en diseño es un desafío difícil de abordar (Henriksen et al., 2017). El diseño en sí mismo es un proceso multifacético, desordenado y complejo (Brown & Wyatt, 2010; Dym et al., 2005; Razzouk & Shute, 2012; Teal, 2010) que promueve lo divergente en un entorno convergente, y coloca, por un lado, al docente en una posición de incertidumbre (López, 2008) obligándole a cambiar el enfoque tradicional; y, por otro, al estudiante que permuta de un rol pasivo a activo. Por ello, dado que cambiar este enfoque no es sencillo, se ha detectado la necesidad de apoyar al profesorado y al alumnado con soluciones y enfoques sostenibles desde el punto de vista de esta disciplina (Elwood et al., 2016; Henriksen et al., 2017; Hernández-Leo et al., 2017; Hoogveld et al., 2005; Jordan, 2016; Norton & Hathaway, 2015; Retna, 2016).

1.1.4. *Design Thinking* en la formación al profesorado

En este contexto que Jordan (2016) define como trayectorias educativas cambiantes, el papel del profesorado resulta crucial. La labor del personal docente no solo implica transmitir conocimiento a su alumnado, sino que también debe apoyar el desarrollo de sus habilidades. Además, su labor es fundamental para formar al alumnado sobre cómo crear y vivir en un mundo sostenible (Ashmann & Franzen, 2017; Fien, 1995; Sund, 2016). Por tanto, el profesorado debe adoptar nuevos roles como entrenador, proveedor de recursos y diseñador (Hoogveld et al., 2005; López, 2008; McKenney et al., 2015; Razzouk & Shute, 2012).

En la práctica, el profesorado enfrenta desafíos complejos y variados como el diseño de lecciones y planes de estudio, el desarrollo de materiales didácticos y metodologías, la motivación del alumnado o el clima escolar (Henriksen et al., 2017), entre otros. Asimismo, el profesorado debe adaptarse a las necesidades de su alumnado y a las características del contexto en el que desarrollan su labor docente (Hernández-Leo et al., 2017; Kerr, 1981; McKenney et al., 2015). De hecho, se debe alentar al profesorado para que comprenda e interiorice la relación entre su labor docente y los problemas de la sociedad (Henriksen et al., 2017).

En este sentido, se puede afirmar que el profesorado continuamente formula y trata problemas de diseño; por lo que diferentes autores abogan por considerar la enseñanza como una ciencia del diseño (Jordan, 2016; Laurillard, 2013; McKenney et al., 2015). Esta conexión entre enseñanza y diseño refuerza la concepción de formar a docentes como diseñadores (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). De hecho, Mishra y Koehler (2006) desarrollaron su reconocido enfoque del conocimiento tecnológico pedagógico del contenido, *Technological pedagogical content knowledge* (TPACK), respaldado por el concepto de educadores como diseñadores. Por tanto, el futuro personal docente necesita estar preparado y capacitado con habilidades de pensamiento crítico, resolución de problemas, y colaboración (Şendağ & Odabaşı, 2009); y precisamente, el *Design Thinking* implica un proceso de aprendizaje en equipo, que facilita el enfoque constructivista, ofrece una visión de alto nivel y fomenta las habilidades del siglo XXI (Goldman & Zielezinski, 2016; Pande & Bharathi, 2020; Stokholm, 2014).

Esta tendencia no es nueva, varias investigaciones han introducido pedagogías basadas en el diseño en la formación de docentes (Elwood et al., 2016; Henriksen et al., 2017; Hernández-Leo et al., 2017; Jordan, 2016; Kali & Ronen-Fuhrmann, 2011; Stevenson et al., 2019). Estas investigaciones defienden la integración del *Design Thinking* en la educación desde el núcleo, capacitando al profesorado para identificar problemas y desarrollar soluciones en el entorno educativo. Sin embargo, a pesar de que existe un amplio discurso y un creciente interés por formar al futuro personal docente en diseño, aún falta investigación y conocimiento (Elwood et al., 2016; Henriksen et al., 2017; Hernández-Leo et al., 2017; Jordan, 2016; Lor, 2017; McKenney et al., 2015). A nivel práctico, los programas de enseñanza y currículos rara vez incluyen este tipo de formación (Elwood et al., 2016; Gleason & Cherrez, 2021; Henriksen et al., 2017; Jordan, 2016; Kali et al., 2015; Kerr, 1981; McKenney et al., 2015). Por tanto, en general, el futuro personal docente no cuenta con las competencias adecuadas para llevar a cabo esta compleja tarea de diseño (Hernández-Leo et al., 2017; Hoogveld et al., 2005; Laurillard, 2013; Torra et al., 2012; Vigo & Soriano, 2014). Esta carencia tal vez se deba a que la integración del ámbito del diseño en la educación no es directa, y supone un desafío; entre otros, el futuro personal docente se considera novato en este ámbito, ya que no tiene experiencia previa en diseño y no ha establecido patrones de diseño básicos para aplicar en su futura labor (Elwood et al., 2016).

Por tanto, se necesitan soluciones prácticas para facilitar la integración natural del *Design Thinking* en la formación del futuro personal docente. Esta capacitación permitiría al futuro personal docente (1) desarrollar sus propias competencias transversales, (2) aplicar esta disciplina adecuadamente en su futuro trabajo docente con su alumnado, y (3) brindar soluciones a los problemas complejos que enfrentan en su trabajo diario, como la creación de materiales didácticos, lecciones y experiencias de aprendizaje. Así, esta formación implicaría una integración natural del *Design Thinking* en el entorno educativo, desde el núcleo.

Para ello, desde el campo del diseño se deben aportar bases, enfoques y herramientas científicas, que emanen en soluciones prácticas para ser aplicadas e integradas en la formación inicial del profesorado. En este sentido, tal y como se ha mencionado, la base visual de las herramientas de diseño ofrece un lenguaje universal que, bien utilizado, constituye una gran vía de comunicación (Blanco, 2016). No obstante, esta ventaja ha llevado a una cierta simplificación excesiva del *Design Thinking*, junto con la falta de preparación de las personas facilitadoras y la existencia de cursos en serie (Blanco, 2016; Lindberg et al., 2010). Por estas razones, aunque el *Design Thinking* parezca extremadamente accesible, en esta tesis se aboga por perfiles desarrolladores con bases sólidas en diseño, personas facilitadoras experimentadas, proyectos híbridos con perfiles expertos en los diferentes campos, y la investigación y análisis del entorno y sus participantes; en este caso, el entorno educativo.

1.1.5. Gestión de proyectos educativos de *Design Thinking*

Un desafío fundamental para la aplicación del *Design Thinking* en los entornos educativos, y especialmente con el futuro personal docente considerado novato en esta disciplina, se relaciona con la dificultad de gestionar proyectos de diseño con grandes grupos de estudiantes, así como la planificación a largo plazo de dichos proyectos. En primer lugar, para el profesorado responsable de la formación del futuro personal docente, que debe gestionar grandes grupos incluyendo su organización, planificación, seguimiento y retroalimentación. En segundo lugar, para el futuro personal docente, que actúa como alumnado que debe adquirir la competencia de trabajo en equipo, necesaria en su aprendizaje e imprescindible en su futura labor (De Prada et al., 2022; Riebe et al., 2010).

Asimismo, es importante considerar los requerimientos de las múltiples interacciones que se producen entre docente-docente, docente-estudiante, y estudiante-estudiante. En primer lugar, la interacción docente-docente debe ser colaborativa (Goddard et al., 2007). Es deseable que el profesorado provenga de diferentes ambientes de trabajo o disciplinas; deben cruzar sus propias islas de conocimiento para establecer un terreno común y un entendimiento compartido (Blanco et al., 2017a). Asimismo, la interacción docente-estudiante debe asegurar una comprensión compartida. El profesorado debe implicar activamente al alumnado y establecer un clima que evite la división entre docentes y estudiantes, haciendo que el alumnado se relaje y se involucre en las actividades de forma desinhibida. Por tanto, el profesorado debe fomentar el interés y la participación, permitiendo errores y acogiendo opiniones, curiosidades, preguntas y respuestas (Fasko, 2001; Feldhusen & Treffinger, 1985). Finalmente, la interacción estudiante-estudiante debe ser adecuada para lograr el trabajo en equipo, considerando que pueden provenir de diferentes realidades. El alumnado debe aprender a trabajar como un equipo cohesivo a través de una comunicación fluida, una colaboración estructurada (Lingard & Barkataki, 2011) y un manejo adecuado de las diferentes situaciones que pueden surgir entre los diferentes miembros del equipo (Oakley et al., 2004).

Estas interacciones se ven influenciadas especialmente en situaciones remotas, como la vivida durante la pandemia del COVID-19. Esta circunstancia implicó que, en solo unos días y de manera abrupta, docentes de diferentes disciplinas trabajaran juntos hacia el aprendizaje remoto (Tejedor et al., 2021b). El concepto de aprendizaje remoto se entiende como la oportunidad de proporcionar una educación al alumnado sin estar físicamente en el mismo lugar que el profesorado a través de la tecnología (Baranova et al., 2021). Así, el aprendizaje remoto implica que alumnado y profesorado permanezcan conectados, pero cambiando las interacciones de físicas a virtuales, lo cual es una necesidad en tiempos de confinamiento (Ali, 2020), ya que evita que el alumnado experimente contratiempos durante el cierre de las escuelas (Morgan, 2020).

La mayoría de las instituciones educativas tienen a su disposición plataformas de gestión del aprendizaje como Moodle, Blackboard o Canvas (Carvalho et al., 2011; Kraleva et al., 2019). Además, se ha incrementado el uso educativo de software más específico para la gestión del trabajo de grupos de estudiantes durante la realización de proyectos. Por ejemplo, Havazík y Pavlíčková (2020) aplican el software Jira (versión 8.13, Atlassian, Sidney, Australia) a estudiantes de Ciencias de la Computación para desarrollar un proyecto para crear un juego de computadora. Collaguazo et al. (2020) utilizan el software Asana (versión 9.24.0, Asana Inc., San Francisco, CA, EE. UU.) con estudiantes de Ingeniería Telemática para desarrollar aplicaciones móviles. Gatwood et al. (2021) evalúan la aceptación del alumnado de farmacia y utilizan una plataforma de productividad basada en la nube (Evernote Business). Rysavy y Michalak (2020) utilizan el software Notion (versión 2.16, Notion Labs Inc., San Francisco, CA, EE. UU.) para administrar a cada miembro de la biblioteca académica durante la pandemia de COVID-19. Zhu y Ryzhkov (2021) aplican el software KanbanFlow (versión 2.0, Codekick, Gotemburgo, Suecia) para gestionar un proyecto de un programa especializado para licenciados. Asimismo, Phillips et al. (2021) implementan el software Slack (versión 4.25.0, Slack Technologies, San Francisco, CA, EE. UU.) para crear una comunidad en línea de estudiantes de medicina.

En esta línea, la implementación de redes sociales en la educación, como *Twitter, blogs, Facebook o YouTube*, tiene potencial para mejorar la enseñanza y el aprendizaje de proyectos. Como Withell et al. (2012) o Caruso (2011) demuestran, las redes sociales pueden ofrecer la oportunidad de investigar las experiencias, reflexionar y escribir libremente, registrar y revisar el proceso, así como compartir o colaborar. Todas estas oportunidades son fundamentales para los proyectos de diseño, que implican investigar, empatizar con la persona usuaria, recopilar información sobre la marcha (Withell et al., 2012) y, sobre todo, colaborar y participar activamente durante el proceso (Caruso, 2011). Sobre estos ejemplos de herramientas de gestión de proyectos y redes sociales, se observa cómo, en general, las soluciones de software utilizadas no se desarrollaron inicialmente para el entorno educativo. Así, este tipo de software necesita considerar premisas educativas para adaptarse a las necesidades pedagógicas (Tuhkala & Kärkkäinen, 2018).

Asimismo, este proceso de enseñanza-aprendizaje no debe consistir en subir el material existente o digitalizar los procesos haciendo lo mismo que antes (Jang, 2009); sino que requiere una transformación digital, rediseñando los procesos e involucrando a las personas. De hecho, en su estudio, Tejedor et al. (2021a) muestran cómo el alumnado denunció la falta de adecuación de los materiales en la crisis del COVID-19, asegurando que eran exactamente iguales que en la etapa presencial. Por tanto, una sociedad sostenible requiere adoptar esta transformación digital, lo cual implica cambios profundos y adaptaciones en las tecnologías educativas emergentes, las innovaciones y la investigación (Cerdá Suárez et al., 2021; Tejedor et al., 2021a). Así, el COVID-19 ha supuesto un cambio sustancial hacia nuevos modelos de enseñanza y aprendizaje (Alam, 2020; Ali, 2020; Burgos, 2020; Kalantzis & Cope, 2020; Sánchez-Cruzado et al., 2021) más centrados en el alumnado (Victorino et al., 2022).

1.1.6. Las Tecnologías de la Información y la Comunicación (TIC) en educación

De esta forma, en esta transición hacia nuevos modelos de aprendizaje, las Tecnologías de la Información y la Comunicación (TIC) destinadas a crear y compartir ideas y contenidos (Henriksen et al., 2016; Lombardi, 2007) son una oportunidad y tienen un papel fundamental en la sociedad sostenible (Sánchez-Cruzado et al., 2021). Si las TIC ya habían cambiado nuestras vidas (Bilbao-Osorio et al., 2013), la pandemia del COVID-19 las ha impulsado en la educación todavía más (Salas-Rueda et al., 2022), haciendo que, por ejemplo, el sector de *startups ed-tech* crezca exponencialmente (Edtech, 2022).

Las TIC favorecen el desarrollo de competencias del siglo XXI (Lewin & McNicol, 2015), se consideran claves para la innovación (Tejedor et al., 2021a) y deben trabajar en estrecha colaboración con el *Design Thinking* (Goto et al., 2014). De hecho, como afirman Stolaki y Economides (2018), para tener una sociedad innovadora sostenible, las nuevas tecnologías, la educación y la formación en creatividad deben estar vinculadas e integradas en sistemas educativos y de formación eficaces. Por tanto, las TIC sirven como palanca para la educación sostenible, empoderando a los estudiantes para que promuevan sus habilidades digitales como futuros ciudadanos (Carrión-Martínez et al., 2020).

Según Gómez (2018), las TIC se consideran herramientas cognitivas, es decir, instrumentos que se apoyan en el aprendiz para generar conocimiento, colocando la responsabilidad en el aprendiz y no en la computadora. Así, de acuerdo con

Jonassen (1994), las herramientas cognitivas deben apoyar la construcción colaborativa del conocimiento. Esto implica aprender con la tecnología, es decir, usar la tecnología como una herramienta de aprendizaje más que como un recurso educativo (Jonassen, 2000). Para utilizar de manera eficiente las TIC en el entorno educativo, de acuerdo con el enfoque de Mishra y Koehler (2006), el profesorado debe considerar el conocimiento de contenidos específicos de la materia, las estrategias pedagógicas para su enseñanza, y el uso de las TIC.

Por tanto, es esencial que el futuro personal docente aumente su alfabetización tecnológica. La alfabetización tecnológica implica adquirir habilidades transformadoras y expansivas para una sociedad sostenible desde las perspectivas cultural, económica, ambiental y social. Así, las competencias docentes digitales sirven para construir una ciudadanía digital (Colás-Bravo et al., 2021), y debido a la relevancia e interés de usarlas de manera efectiva en las aulas, en general, el futuro personal docente precisa aumentar su conocimiento en las TIC y sus numerosas aplicaciones (Blasco-Serrano et al., 2022; Gibson et al., 2014; Mourlam et al., 2019; Saini & Abraham, 2019). En consecuencia, es esencial capacitar al futuro personal docente en alfabetización tecnológica para que integre la tecnología en sus aulas de manera efectiva (Admiraal et al., 2017; Baylor & Ritchie, 2002; Bers et al., 2019). Por tanto, se detecta la necesidad de seguir avanzando en el desarrollo y aplicación de la tecnología como herramienta de aprendizaje (Blaso-Serrano et al., 2022; Henriksen et al., 2016).

1.1.7. *Sketching* y creatividad

Además de la tecnología, existen otras formas complementarias de crear y compartir ideas, como la expresión mediante bocetos. La competencia transversal de expresar y comunicar con bocetos es una de las más relevantes en el contexto de la ingeniería, y especialmente en el campo del diseño y el *Design Thinking* (Booth et al., 2016; Eissen & Steur, 2012; Hilton et al., 2017). El bocetaje o *sketching* permite a los diseñadores desarrollar, externalizar, registrar y comunicar las ideas que tienen en mente, así como generar otras muchas nuevas (Gryaditskaya et al., 2019). En consecuencia, los bocetos tienen un papel esencial en el proceso de diseño, como por ejemplo durante las fases de ideación o conceptualización. Por tanto, existe una fuerte relación entre *sketching y Design Thinking.*

En esta línea y como eje de esta tesis, la competencia transversal de la creatividad y el *sketching* están estrechamente relacionadas (Van der Lugt, 2005). La expresión a través del boceto favorece la resolución creativa de problemas, ya que el pensamiento visual proporciona las analogías necesarias para desarrollar nuevas estructuras (Verstijnen et al., 1998). En consecuencia, la mayoría de los procesos creativos utilizan ampliamente el pensamiento visual y, por lo tanto, bocetar se considera un medio para estimular el pensamiento creativo.

Sin embargo, a pesar de las potencialidades de la competencia del *sketching*, no es sencilla de enseñar y desarrollar. Durante la infancia, los niños dibujan sin importarles si lo hacen bien o mal; sin embargo, este lenguaje y espontaneidad se pierden cuando se les instruye (Llorente, 2021). La mayoría de los ambientes académicos generalmente consideran el dibujo y la creatividad como un pasatiempo en la práctica (Jenny, 2013). En niveles educativos superiores, como en el ámbito de la ingeniería de diseño o en los grados de magisterio, existen asignaturas relacionadas con la expresión artística o la expresión plástica y visual. Sin embargo, la mayoría del alumnado de primer año que se enfrenta a estas asignaturas, no utiliza el dibujo como medio de comunicación desde hace años, y su formación previa es fundamentalmente técnica. El intento de alcanzar la perfección o el hiperrealismo en sus dibujos les genera un bloqueo que les impide desarrollar esta competencia de comunicación espontánea.

Como resultado, muchos estudiantes a menudo usan solo lenguaje verbal para comunicar sus ideas. Este efecto se debe en parte a que, según Norp y Van Hoek (2019), muchas veces durante la formación, el alumnado pasa horas creando el dibujo final más excelente y realista que pueden lograr. Sin embargo, esto no está alineado con la práctica profesional. Para su futuro, es más útil expresarse a través de bocetos rápidos y colaborativos, fomentando la comunicación entre los participantes del equipo de trabajo a través de un terreno común de discusión: el boceto. Por tanto, es necesario trabajar para alinear mejor la relación entre la formación y la práctica profesional. Se necesitan soluciones prácticas para ayudar al profesorado a fomentar la expresión creativa a través del boceto como lenguaje universal.

1.2. Definición objetivos de investigación

A partir de las necesidades identificadas a lo largo de la revisión bibliográfica, se definen los objetivos de esta investigación (Tabla 1). El objetivo general es avanzar en nuevas estrategias para fomentar competencias transversales como la creatividad en entornos educativos; creatividad entendida como capacidad de combinar los conocimientos aprendidos para resolver problemas o crear cosas. Esta tesis pretende dar respuesta a este ideal a través del análisis y aprovechamiento del campo del *Design Thinking* y de herramientas basadas en el terreno de las TIC y el *sketching.* Para ello, se plantean los objetivos específicos de investigación (objetivos 1-5). A cada objetivo (OBJ) se le ha asignado una nomenclatura para su identificación unívoca a lo largo de la tesis.

Tabla 1. *Objetivos de investigación.*

Objetivos	Descripción
Objetivo general	Avanzar en nuevas estrategias para fomentar competencias transversales como la creatividad, entendida como un proceso de resolución de problemas, en entornos educativos.
OBJ1	Definir un marco teórico basado en factores para diseñar, desarrollar y evaluar nuevas estrategias metodológicas que ayuden a fomentar la creatividad en entornos educativos.
OBJ2	Diseñar, desarrollar y validar una nueva estrategia metodológica basada en *Design Thinking* para ayudar al profesorado a promover competencias transversales como la creatividad en el alumnado.
OBJ3	Diseñar, desarrollar y validar una nueva estrategia metodológica para formar al futuro personal docente en *Design Thinking* para ayudarles a enfrentar problemas prácticos de su día a día como diseñadores.
OBJ4	Analizar y aprovechar el potencial de la tecnología y las TIC como herramienta de aprendizaje para integrar de manera natural las metodologías desarrolladas en entornos educativos.
OBJ5	Analizar y aprovechar el potencial del *sketching* como herramienta de aprendizaje para promover la expresión creativa del alumnado.

1.3. Contexto

El nacimiento de esta tesis surge de la conexión entre 3 pilares: una motivación personal, una base teórica consistente procedente de la literatura y un entorno con experiencia en proyectos de investigación.

A nivel personal, y como ingeniera de diseño industrial, hace tiempo que mi formación y mi experiencia me llevaron a razonar que no solo las personas que diseñamos debemos detectar, enfrentar y resolver desafíos complejos, sino que, en cualquier ámbito o disciplina es necesario. Como se ha descrito anteriormente, el alumnado del sigo XXI tienen acceso directo con solo un clic a toda la información. Por tanto, en la era digital actual, la educación no solo implica transmitir conocimiento al estudiante; sino que debe potenciar un modelo educativo basado en el aprendizaje por competencias, en el que el alumnado adopta una postura proactiva y sin miedo al fracaso, y en el que el profesorado no tiene la necesidad de tener todas las respuestas.

Este paradigma me cautivó y me llevó a empezar mi actividad en el Grupo de Investigación Human Openware (Howlab) del Instituto de Investigación en Ingeniería de Aragón (I3A), dentro de la Universidad de Zaragoza, reconocido por el Gobierno de Aragón con la referencia T-90. Comencé dando los primeros pasos en el Trabajo Fin de Máster, el cual permitió esbozar las posibilidades de la hipótesis planteada, su viabilidad y la capacidad de impacto. En este marco, se solicitó en enero de 2018 la convocatoria de subvenciones destinadas a la contratación de personal predoctoral en formación, la cual fue concedida durante ese mismo año. La concesión de este proyecto fue una oportunidad para llevar a cabo la presente tesis, ya que permitió financiar la duración de los estudios de doctorado. Así, este trabajo ha sido subvencionado por el Gobierno de Aragón, en el marco de la Subvención BOA2018-0615027, lo que ha permitido recibir formación y participar en docencia y en proyectos relacionados con la temática de tesis, tal y como recoge el Anexo I.

Howlab es un grupo de investigación formado por integrantes procedentes de los ámbitos de la ingeniería de diseño industrial y desarrollo de producto; de la ingeniería electrónica y comunicaciones; de la ingeniería informática; y de la ingeniería de telecomunicaciones. Esto es clave para el desarrollo de esta tesis, ya que el grupo tiene amplia experiencia en proyectos de investigación de carácter "x-disciplinar", término acuñado por Blanco (2016) para asignar al conjunto de posibilidades de trabajo colaborativo: multi-, cross-, inter-, trans-; siendo esta tesis una sinergia entre las disciplinas de la ingeniería de diseño, la tecnología y la educación. Los proyectos que se impulsan desde el grupo siguen dos líneas básicas de investigación: tecnología para el Internet of Things (IoT) y metodologías de diseño de productos y servicios. Estas líneas generan valor en la creación de soluciones para mejorar el bienestar de las personas, con especial énfasis en la salud y la educación. Así, esta tesis supone un impulso para esta línea de investigación dentro del grupo.

Para completar la x-disciplinaridad de esta tesis, las líneas de trabajo han discurrido en relación con la Facultad de Educación de la Universidad de Zaragoza, concretamente con el Departamento de Ciencias de la Educación y con el Grupo de

Investigación Educación y Diversidad (EDI), reconocido por el Gobierno de Aragón con referencia S-49. Estas líneas de colaboración han permitido llevar a cabo multitud de sesiones conjuntas que han sido esenciales para detectar y recoger necesidades; y han concluido en la aplicación x-disciplinar en las nuevas estrategias propuestas. La figura 5 muestra gráficamente la interrelación entre las disciplinas del diseño, la educación y la tecnología, así como los niveles educativos en los que se han aplicado las nuevas estrategias como parte de la investigación dentro del desarrollo de la tesis.

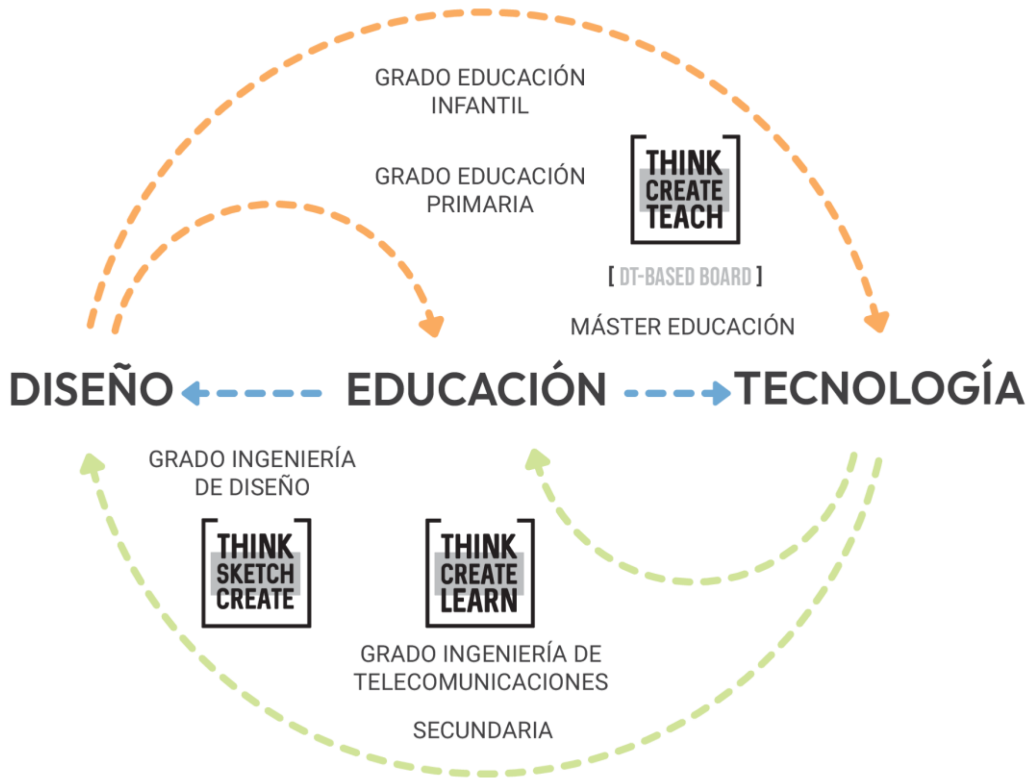


Fig 5. Disciplinas y escenarios involucrados en la experimentación.

A continuación, se describe el contexto particular donde se han implementado y evaluado de manera x-disciplinar las nuevas estrategias desarrolladas (Figura 5) que se presentarán a lo largo de las siguientes secciones:

- *Think-Create-Learn* que corresponde al estudio 1, se aplica en Educación Secundaria Obligatoria (ESO) y en Enseñanzas universitarias; concretamente en el Grado en Ingeniería de Tecnologías y Servicios de Telecomunicación.
- *Think-Create-Teach* apoyada en un tablero online (*DT-based board),* que corresponde a los estudios 4 y 5, se aplica en las Enseñanzas universitarias de Grado en Magisterio en Educación Infantil; Grado en Magisterio en Educación Primaria; y Máster Universitario en Profesorado de Educación Secundaria Obligatoria, Bachillerato, Formación Profesional y Enseñanzas de Idiomas, Artísticas y Deportivas, especialidad de Tecnología e Informática. Su utilización con futuro personal docente implica que los proyectos desarrollados se apliquen a Educación Infantil, Educación Primaria, ESO y Bachillerato.

- *Think-Sketch-Create* que corresponde al estudio 6, se aplica en el Grado en Ingeniería de Diseño Industrial y Desarrollo de Producto.

En base a los contextos de aplicación mencionados, se puede observar que las nuevas estrategias desarrolladas alcanzan un espectro amplio de niveles educativos. El hecho de que el trabajo realizado en esta tesis sea aplicado en proyectos de asignaturas reales, que tienen su propia planificación, objetivos y tiempo determinado, ha implicado buscar el equilibrio entre el desarrollo de la propia investigación y los requerimientos de cada asignatura.

1.4. Metodología

Desde una perspectiva general, esta tesis se encuadra en el método científico. Concretamente se sigue una estrategia de investigación entendida como una iteración de ciclos de diseño y evaluación. Los estudios presentados combinan, por un lado, el diseño de nuevas estrategias para el ámbito educativo y por otro, su evaluación práctica en entornos reales (testeo). Para el diseño de las nuevas estrategias se trabaja con equipos x-disciplinares, que permiten considerar los puntos de vista educativo, de diseño y de tecnología. Esto es fundamental, ya que esta tesis es una sinergia que parte del ámbito de la ingeniería de diseño y se inserta en el ámbito educativo. El testeo en entornos reales genera, tras cada iteración, conocimiento profundo sobre el efecto y las percepciones de las nuevas estrategias en el alumnado y el profesorado, favoreciendo su mejora a partir de la información recopilada.

Este proceso iterativo se encuadra bajo la línea metodológica del *Design Thinking,* que, a la vez de ser el núcleo de las nuevas estrategias a diseñar, nutre y guía esta tesis en los procesos de diseño y evaluación. Este enfoque supone un balance entre la teoría (investigación epistemológica) y praxis (investigación aplicada), que se alternan para generar conocimiento (Blanco, 2016). Por tanto, el conocimiento de esta investigación se basa en la realización de estados del arte, análisis y sesiones de codiseño para el diseño de las nuevas estrategias, así como en la observación y aprendizaje durante su aplicación, alcanzando un equilibrio entre praxis y avance científico.

El *Design Thinking* se considera una vía para el cambio educativo (Brundiers et al., 2021) y se caracteriza por colocar a las personas usuarias, en este caso a estudiantes y docentes, en el centro; esto permite empatizar y entender las necesidades de las personas usuarias en profundidad para así diseñar y evaluar las herramientas de manera óptima. Asimismo, el *Design Thinking* tiene un carácter participativo; proporciona procesos flexibles que ayudan a los equipos x-disciplinares en las tareas de definición, ideación, prototipado, testeo o análisis crítico.

Concretamente, en esta investigación se aplica el proceso iterativo representado en la Figura 6, basado en el modelo de *Double Diamond* (Design Council, 2021). El *Double Diamond* es un modelo sintetizado del *Design Thinking:* el primer rombo implica explorar un tema en profundidad (pensamiento divergente) para luego enfocarse en un desafío (pensamiento convergente), y el segundo rombo implica proporcionar diferentes respuestas al desafío (pensamiento divergente) para luego definir la solución (pensamiento convergente).

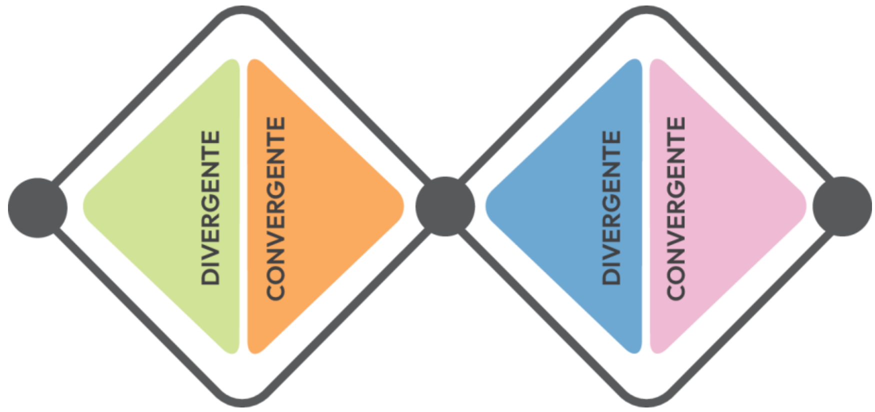


Fig 6. Metodología Double Diamond.

Considerando el marco metodológico general descrito, hay que señalar que cada uno de los estudios de esta tesis sigue una metodología de investigación específica de acuerdo con sus objetivos. No obstante, en todos los estudios se ha utilizado para la evaluación de las nuevas estrategias la metodología Xassess (Blanco et al., 2016). Así, se han adaptado las cinco dimensiones de Xassess (*when, why, who, what and how*) para la evaluación de nuevas herramientas en el entorno educativo. A continuación, se incluye una recopilación de los aspectos comunes de las evaluaciones x-disciplinares realizadas en los estudios, de acuerdo con la adaptación de las dimensiones de Xassess:

- *When:* Esta dimensión responde a cuándo evaluar el recurso, incluyendo el marco y escenario. Las nuevas estrategias incluidas en los estudios de esta tesis se encontraban en una fase del proyecto avanzada, con calidad suficiente para que la evaluación pudiese llevarse a cabo de manera correcta en el entorno educativo.

- *Why:* Esta dimensión atiende a la motivación y objetivo de la evaluación. En el caso de los estudios de esta tesis, a nivel general, se sitúan los objetivos de (1) validar el cometido de las nuevas estrategias con estudiantes y docentes reales; y de (2) obtener la retroalimentación necesaria para la mejora y la toma de decisiones para el diseño final de un producto finalista y susceptible de someterse a una evaluación más en masa.

- *Who:* Esta dimensión implica definir todas las personas involucradas en la evaluación. En los estudios de esta investigación, el proceso de evaluación se llevó a cabo desde el inicio de manera colaborativa entre las diferentes disciplinas (diseño, educación y tecnología). Esto supuso un reto multidisciplinar a todos los niveles, considerando al profesorado como personas usuarias y también como parte del equipo. De hecho, en varios de los estudios, ambos niveles, a quién y quién, se fusionan en algunos puntos: parte del equipo x-disciplinar evalúa al profesorado; que, a su vez, junto con el equipo x-disciplinar son evaluadores del alumnado; quienes a su vez evalúan la nueva estrategia. En cuanto a las poblaciones analizadas, el muestreo (cómo los participantes fueron seleccionados) fue intencional (*purposive sampling*) (Lodico et al., 2010), una técnica en la que el equipo x-disciplinar utilizó su propio juicio para elegir a los miembros de la población a participar de acuerdo con los objetivos concretos de cada estudio.

- *What:* Esta dimensión responde a qué factores y dimensiones evaluar. En los estudios de esta tesis se comprueba si las estrategias desarrolladas contribuyen en la formación de competencias transversales como la creatividad. Sin embargo, evaluar este aprendizaje basado en competencias no es sencillo (Geisinger, 2016; Toomey et al., 2017). Es cierto que existen multitud de estudios centrados en la elaboración de métricas para evaluar la creatividad (Ibáñez, 1998), analizando cómo de creativa es una persona a partir de indicadores como el número o la calidad de las ideas. Una posibilidad en la evaluación podría haber sido aplicar una de estas métricas y dar una "calificación", pero ello favorece la competición entre el alumnado y antepone la motivación extrínseca a la intrínseca. Por ello, en estos estudios no se consideró "medir" la creatividad o la "cantidad" de competencias transversales, sino asegurarse de guiar al alumnado de manera natural en trabajar y desarrollar el trabajo en equipo, el análisis, la empatía, el pensamiento divergente, la participación, la motivación intrínseca, la toma de decisiones, la reflexión, la redefinición o comunicación, entre otras.
- *How:* Esta dimensión indica cómo y con qué técnicas se va a evaluar. Se utilizaron generalmente métodos mixtos (cualitativos y cuantitativos) para evaluar las nuevas estrategias. La evaluación se llevó a cabo a partir de la recopilación de información de las personas usuarias antes, durante y después de la aplicación práctica. Se utilizaron técnicas de encuesta con preguntas cerradas y abiertas (cuantitativa y cualitativa), entrevistas semiestructuradas (cualitativa), observación con notas de campo (cualitativa), o datos extraídos de la plataforma de gestión de proyectos (cuantitativa), entre otras. Para el análisis de datos, se utilizaron diferentes métodos de agrupación, síntesis e interpretación. Las entrevistas fueron transcritas y codificadas según el enfoque de análisis temático (Patton, 2014). Las transcripciones fueron leídas varias veces por separado por cada miembro del equipo para asegurar una interpretación precisa (Merriam, 1988). Durante este proceso se utilizaron herramientas como MS-Word o Adobe Illustrator. Por otra parte, los resultados cuantitativos se exportaron a MS Excel y se analizaron mediante estadísticas descriptivas y gráficos visuales realizados con Python 3.8. En aquellos casos en los que hubo que detectar diferencias significativas y hacer inferencias estadísticas, los datos fueron analizados utilizando el software IBM SPSS Statistics Versión 24.0.

Con todo ello, se puede afirmar que el marco metodológico basado en el *Design Thiking* y la estrategia de evaluación Xassess, así como las pautas específicas de cada estudio de muestreo, evaluación o análisis de datos, soportan la veracidad, precisión y rigor de esta investigación, y pueden servir como base para otros estudios que se lleven a cabo en el futuro.

2. Esquema de tesis

En esta sección se presentan los estudios publicados incluidos en el compendio (2.1) y la justificación temática de los mismos (2.2).

2.1. Presentación de los estudios publicados

Esta tesis doctoral está compuesta por un compendio de seis publicaciones científicas. En adelante, estas publicaciones se presentan como estudios numerados del 1 al 6. Los estudios se enmarcan en los objetivos de investigación descritos y en las necesidades derivadas de la investigación. No obstante, cada uno de ellos responde a unas necesidades concretas y aporta conocimiento específico, por lo que pueden ser entendidos también de manera independiente. A continuación, se presenta cada uno de los estudios, incluyendo un resumen que lo contextualiza en la investigación global de esta tesis.

- **Estudio 1:** Calavia, M. B., Blanco, T., & Casas, R. (2021). Fostering creativity as a problem-solving competence through design: Think-Create-Learn, a tool for teachers. *Thinking skills and creativity, 39,* 100761.
  https://doi.org/10.1016/j.tsc.2020.100761

  En el estudio 1 se explora qué se debe considerar para fomentar la creatividad en las aulas. A partir de esta revisión bibliográfica, se definen 15 factores clave de la creatividad a tener en cuenta a la hora de diseñar un nuevo recurso para el aula: incorporación al currículo, practicidad, novedad, clima, estimulación, análisis, cooperación, motivación intrínseca, participación, flexibilidad, incertidumbre, tiempo de reflexión, divergencia, autoevaluación y redefinición. Con base en estos indicadores, y como fruto de la estrecha colaboración con docentes de diferentes ciclos formativos, este estudio propone una nueva estrategia metodológica denominada *"Think-Create-Learn"* (TCL). Esta metodología está compuesta por herramientas abiertas, accesibles e intuitivas basadas en el diseño. TCL tiene como objetivo ayudar al profesorado a aplicar el *Design Thinking* en el aula, centrándose en transformar el conocimiento en la resolución de problemas, con el fin de fomentar la capacidad creativa del alumnado y establecer nuevas posibilidades para el modelo educativo basado en el aprendizaje por competencias. La evaluación en un entorno real, con docentes y estudiantes, demostró que la metodología TCL contempla los factores propuestos, se integra positivamente en el currículo y ayuda al profesorado a "producir" personas más creativas, fomentando el aprendizaje basado en competencias.

- **Estudio 2:** Calavia, M.B., Blanco, T., & Casas. R. (2019). Recursos basados en el diseño para fomentar la creatividad en el aula. In *V International Conference on Learning, Innovation and Competitiveness (CINAIC)* (pp. 590-595). Madrid, España.
  http://dx.doi.org/10.26754/CINAIC.2019.0120

  El estudio 2 es un primer acercamiento para construir el estudio 1, puesto que se lleva a cabo una primera aproximación de la metodología TCL. Concretamente, se presenta una experiencia innovadora de aprendizaje basada en el *Design Thinking.* La experiencia se fundamenta en entregar a un docente la primera versión de una herramienta desarrollada que pretende ayudar al profesorado en el fomento del aprendizaje por competencias a través del *Design Thinking*. De esta forma, la herramienta es aplicada por un docente externo en un temario y clase aleatoria; con el objetivo principal de validarla en un contexto real, y obtener retroalimentación necesaria para el diseño final de la siguiente iteración. Para ello, en primer lugar, se presentó la herramienta al docente para mostrarle su cometido. Después, de manera individual, el docente llevó a cabo la fase de preparación y planificación de las actividades a través de la herramienta. Por último, el docente aplicó en su aula las actividades establecidas. A partir de la evaluación de esta experiencia, se demuestra que la disciplina del *Design Thinking* supone una base de conocimiento y de recursos que pueden ser extrapolados y adaptados al ámbito educativo, así como un importante punto de partida en el desarrollo de herramientas innovadoras que favorezcan el fomento de la creatividad.

- **Estudio 3:** Calavia, M.B., Blanco, T., & Casas. R. (2019). Formando a personas creativas en la era digital. Evaluación x-disciplinar de una herramienta basada en el diseño. In Foradada, C. & Irala-Hortal, P. (Eds.), *Re_Visiones sobre arte, patrimonio y tecnología en la era digital,* (pp. 185-194). Gobierno de Aragón.

  El estudio 3 se centra en ofrecer una descripción pormenorizada de cómo evaluar una herramienta educativa basada en el diseño. Por tanto, junto con el estudio 2, este estudio es otra de las bases para construir el estudio 1. Para su desarrollo, esta investigación se basa en la estrategia de evaluación Xassess (Blanco et al., 2016); esta metodología supone un marco teórico-práctico de evaluación de productos y servicios aplicable en cualquier punto del proceso de diseño. En este estudio se adaptaron las cinco dimensiones de Xassess a la idiosincrasia del escenario educativo. Así, durante este estudio se definieron y abordaron las siguientes dimensiones de acuerdo con la evaluación x-disciplinar de una herramienta educativa basada en diseño: *"When"* ¿Cuándo evaluar la herramienta? Concretar el marco y escenario; *"Why"* ¿Por qué evaluar esta herramienta? Precisar la motivación y objetivo; *"Who"* ¿Quién evalúa? ¿A quién se evalúa? Definir las personas involucradas; *"What"* ¿Qué se quiere evaluar? Determinar los factores y dimensiones a evaluar; *"How"* ¿Cómo se va a evaluar? Definir técnicas de evaluación. De esta forma, este estudio afianza implementar una metodología específica para la evaluación de nuevas herramientas educativas basadas en el diseño, desde un planteamiento x-disciplinar.

- **Estudio 4:** Calavia, M. B., Blanco, T., Casas, R., & Dieste, B. (2022). Making Design Thinking for Education sustainable: Training preservice teachers to address practice challenges. *Thinking skills and creativity,* 101199. https://doi.org/10.1016/j.tsc.2022.101199

El estudio 4 presenta la importancia de formar al futuro personal docente para que sea capaz de enfrentar los desafíos educativos de la práctica; su labor no implica únicamente transmitir conocimientos al alumnado, sino que también debe apoyar el desarrollo de sus competencias, adoptando nuevos roles como entrenador, proveedor de recursos y diseñador. Este estudio presenta las bases y la aplicación de una nueva estrategia metodológica denominada *"Think-Create-Teach"* (TCT), desarrollada por un grupo x-disciplinar de especialistas de los ámbitos del diseño, la tecnología y la educación. TCT tiene como objetivo capacitar al futuro personal docente en diseño para que, guiados por el *Design Thinking*, pueda formular sus propios problemas y crear sus propios materiales didácticos. Esta metodología se aplicó y evaluó a través de métodos cuantitativos y cualitativos con un grupo experimental de futuro personal docente. Posteriormente, los procesos y los materiales didácticos desarrollados por el grupo experimental se compararon con los realizados por un grupo control de futuro personal docente (existía paridad entre las muestras) que no utilizó TCT. La evaluación evidenció la validez de TCT para la formación del futuro personal docente en diseño, puesto que el grupo experimental entendió la importancia del proceso y diseñó materiales más adecuados, utilizables y creativos que el grupo control. Así, esta formación es un primer paso que permite al futuro personal docente trabajar sus propias competencias transversales, aplicar la disciplina del diseño y abordar los complejos desafíos de su futura labor docente, como la creación de materiales didácticos.

- **Estudio 5:** Calavia, M. B., Blanco, T., Casas, R., & Dieste, B. (2022). Improving Design Project Management in Remote Learning. *Sustainability, 14*(17), 11025. https://doi.org/10.3390/su141711025

El estudio 5 recoge un tablero en línea basado en *Design Thinking* para mejorar la implementación y gestión de proyectos de diseño en situaciones de aprendizaje remoto. El *Design Thinking* en sí es intrínsicamente complejo, y gestionar su aprendizaje y los proyectos con grupos grandes de estudiantes no es sencillo, especialmente en situaciones remotas como el COVID-19. Esta circunstancia implicó que, de manera abrupta, el profesorado trabajara hacia el aprendizaje remoto; entendido como la oportunidad de proporcionar una educación sostenible al alumnado sin estar físicamente en el mismo lugar que el profesorado a través de la tecnología. Para el aprendizaje remoto, las TIC, destinadas a crear y compartir ideas y contenidos, son clave y suponen una oportunidad. No obstante, su aplicación no debe consistir en subir el material existente tal cual está; sino que se requiere una transformación digital, rediseñando los procesos e involucrando a las personas. Así, a partir de la consideración de necesidades pedagógicas y premisas educativas, se desarrolla un nuevo uso de un tablero en línea a través del software Trello denominado *DT-based board*. Este tablero se aplicó en dos cursos consecutivos de futuro personal docente, quienes además son personas usuarias clave, puesto que es crucial que desarrollen competencias digitales para utilizar la tecnología de manera efectiva en sus aulas hacia una sociedad sostenible. El tablero se percibió como útil para desarrollar proyectos de diseño y mejorar el aprendizaje colaborativo; fue beneficioso para la gestión, el seguimiento y la comunicación. Así, fruto del aprendizaje adquirido, el estudio 5 brinda pautas para diseñar y usar este tipo de tableros, ayudando al personal educador y/o investigador a integrar el *Design Thinking* de manera natural con un proceso replicable y flexible.

- **Estudio 6:** Calavia, M. B., Blanco, T., Serrano, A., Biedermann, A., & Casas, R. (2022). Think-Sketch-Create: Improving Creative Expression Through Sketching. In Gerbino, S., Lanzotti, A., Martorelli, M., Mirálbes Buil, R., Rizzi, C., Roucoules, L. (Eds.), *Advances on Mechanics, Design Engineering and Manufacturing IV. JCM 2022. Lecture Notes in Mechanical Engineering* (pp. 1585-1597). Springer, Cham.

  https://doi.org/10.1007/978-3-031-15928-2_138

  El estudio 6 recoge un método para ayudar al profesorado a fomentar las competencias de bocetaje o *sketching* en el alumnado. En los primeros ciclos de formación, los niños y niñas habitualmente dibujan sin importarles la calidad de sus dibujos; sin embargo, este lenguaje y espontaneidad se pierden cuando se les instruye. Esto resulta contraproducente para multitud de empleos de nuestra sociedad, como es el caso de la ingeniería y el diseño, en donde desarrollar, exteriorizar, registrar y comunicar los pensamientos e ideas a través del boceto es fundamental. Así, basado en el trabajo x-disciplinar, el estudio 6 presenta una nueva estrategia materializada en forma de talleres denominada *"Think-Sketch-Create"* (TSC). TSC tiene el objetivo de ayudar al alumnado a mejorar sus competencias para expresar sus pensamientos e ideas a través del dibujo, alejándoles del bloqueo que les supone el intento de lograr acabados hiperrealistas. Estos talleres constan de dos bloques: calentamiento y experimentación. Los talleres de TSC se aplicaron y evaluaron mediante métodos cualitativos y cuantitativos con estudiantes de ingeniería. La evaluación de TSC demostró su positiva integración en el currículo, su utilidad para establecer un clima adecuado sin miedo al fracaso y su capacidad para ampliar conocimientos competenciales. Así, este estudio evidencia el interés de formar al alumnado para que utilice el boceto como medio de comunicación, así como la necesidad de apoyar al profesorado con nuevos métodos que le ayuden a fomentar la expresión creativa en sus clases.

2.2. Justificación de la unidad temática de los estudios

Los estudios de esta tesis se enmarcan de forma transversal en la búsqueda de soluciones y formas de aprendizaje distintas a la copia, la memoria o la reproducción, que fomenten competencias transversales como la creatividad, entendida en este trabajo como un proceso de resolución de problemas. Para alcanzar este paradigma, en esta tesis se recogen 6 estudios, que se relacionan entre ellos de acuerdo con la figura 7.

Fig 7. Relación entre los estudios presentados.

Como muestra la figura 7, los estudios de esta tesis presentan cuatro nuevas estrategias para los entornos educativos: por un lado, dos metodologías basadas en *Design Thinking* (estudios 1-4); y, por otro lado, dos herramientas de aprendizaje basadas en el terreno de las TIC (estudio 5) y el *sketching* (estudio 6). A continuación, se detalla cómo los estudios presentados en esta tesis se conectan directamente con las necesidades y los objetivos de investigación.

El proyecto de investigación comienza con el estudio 1 que recoge la creación y desarrollo de una nueva estrategia metodológica denominada TCL (*Think-Create-Learn*) basada en *Design Thinking* para ayudar al profesorado a promover competencias transversales como la creatividad en las aulas, hacia un modelo educativo basado en el aprendizaje por competencias (objetivo 2). El nombre de TCL se relaciona directamente con la acción que busca que realice el alumnado: (1) *Think* - pensar y reflexionar sobre una necesidad, (2) *Create* - crear para darle respuesta y (3) *Learn* - aprender a partir del proceso realizado. Asimismo, este estudio desarrolla un marco teórico basado en 15 factores clave de la creatividad a tener en cuenta a la hora de diseñar, desarrollar y evaluar una nueva estrategia para el aula (objetivo 1), que establece las bases de este y el resto de los estudios la tesis.

Los estudios 2 y 3 son un primer acercamiento para construir el estudio 1; así, TCL es la culminación de los estudios 2 y 3. Por un lado, el estudio 2 supone la primera versión de una experiencia innovadora de aprendizaje basada en el *Design Thinking* para trabajar el desarrollo de competencias transversales. Por otro lado, el estudio 3 supone un planteamiento x-disciplinar para la evaluación de nuevas herramientas educativas basadas en el diseño. De esta forma, igual que el estudio 1, los estudios 2 y 3 también se relacionan con los objetivos 1 y 2.

Como consecuencia de la aplicación exitosa de TCL, se realiza una adaptación para la formación del futuro personal docente en diseño (estudio 4). Tal y como se ha descrito en el capítulo introductorio, nos encontramos en un contexto de trayectorias educativas cambiantes, en las que el profesorado es uno de los principales promotores activos del cambio. El profesorado de hoy no solo planea lecciones que incorporan las actividades existentes en el aula y los recursos de instrucción, sino que también diseña y crea nuevas metodologías, clases, materiales didácticos o formas de aprendizaje. Además, fruto de la evaluación de TCL, se observa que, para facilitar la integración natural del *Design Thinking* en el entorno educativo, es necesario formar al futuro personal docente como diseñador.

Así, el estudio 4 presenta una nueva estrategia metodológica denominada TCT (*Think-Create-Teach*), que tiene como objetivo formar al futuro personal docente en *Design Thinking* para ayudarles a enfrentar problemas prácticos de su día a día como la creación de sus propios materiales didácticos (objetivo 3). El nombre de TCT se relaciona directamente con la acción que busca que realice el futuro personal docente: (1) *Think* - pensar y reflexionar sobre una necesidad, (2) *Create* - crear soluciones para darle respuesta y (3) *Teach* - enseñar a partir de la solución planteada.

Los estudios 1-4 implican que la línea de *Design Thinking* sea el grueso de la presente tesis. Esto se debe a que, tal y como se ha señalado en la introducción, el *Design Thinking* se reconoce, per se, como un proceso creativo que puede ayudar a mejorar las competencias transversales.

Asimismo, el desarrollo de esta tesis explora posibles herramientas a partir del terreno de las TIC para facilitar la inserción del *Design Thinking* en educación. La era digital en la que nos encontramos ha ocasionado cambios en la educación y supone una oportunidad como herramienta de aprendizaje para una educación creativa. Asimismo, los avances tecnológicos son clave para situaciones como la pandemia del COVID-19, que supuso adoptar de un día a otro el aprendizaje remoto. En este contexto, a partir de la metodología TCT (estudio 4) que necesitó de un soporte digital ante la situación del COVID-19, nace el estudio 5 enmarcado en la línea de TIC. El estudio 5 presenta un nuevo uso de un tablero en línea a través del software Trello.

Así, el estudio 5 responde al objetivo 4, ya que aprovecha el potencial de las TIC como herramienta de aprendizaje para integrar de manera natural las metodologías desarrolladas en los entornos educativos. Concretamente un tablero en línea basado en *Design Thinking* y premisas educativas (*DT-based board*), que tiene como objetivo ser útil para la implementación y gestión de proyectos de diseño en situaciones remotas.

Como consecuencia de los estudios 4 y 5, y, por tanto, en base a TCT y al tablero en línea, se ha planificado un curso en línea abierto conocido como MOOC (*Massive Open Online Course*). Este curso pretende acercar los resultados de la presente tesis y difundir la formación en diseño al profesorado. De la misma forma, este curso MOOC se alinea con el objetivo 4.

Por último, esta tesis explora posibles herramientas a partir del *sketching,* vinculado directamente con la resolución creativa de problemas. Así, el estudio 6 presenta una nueva herramienta denominada TSC (*Think-Sketch-Teach*), que tiene como objetivo promover la expresión creativa y la comunicación espontánea de los futuros profesionales a través del *sketching* para que sean capaces de expresar sus pensamientos e ideas a través del dibujo (objetivo 5). El nombre de TSC se relaciona directamente con la acción que busca que realice el alumnado: (1) *Think* - pensar y reflexionar, (2) *Sketch* - bocetar lo que tienen en mente para comunicar y (3) *Create* - crear a partir del bocetaje.

Se desprende de los expuesto que los seis estudios dan respuesta a los objetivos inicialmente planteados en esta investigación, avanzando en nuevas estrategias para fomentar competencias transversales como la creatividad en los entornos educativos. Durante esta tesis se han realizado aportaciones desde el *Design Thinking*, las TIC y el *Sketching*, no obstante, son vías que no están cerradas, sino que existen amplias posibilidades: ya sea profundizando en cada una de ellas o abriendo nuevas bajo este marco. En la sección de discusión, se recoge de forma más detallada las contribuciones de los estudios descritos, así como consideraciones acerca de las decisiones tomadas durante el proceso.

3. Relación publicaciones

En esta sección se recogen los seis estudios que conforman el cuerpo de esta tesis. Los estudios 1, 4 y 5 están indexados en *Journal Citation Reports* (JCR), el estudio 2 ha sido publicado en las actas de un Congreso Internacional, el estudio 3 ha sido publicado como capítulo de un libro y el estudio 6 está indexado en *Scimago Journal & Country Rank* (SJR). En relación con la revista científica de cada estudio, se indica la Base de Datos (BD) en la que está indexada, el Factor de Impacto (FI) y las categorías y cuartiles (Q) ordenadas según conexión temática con la tesis. Esta información corresponde al año de publicación, excepto en las publicadas en 2022 (estudios 4, 5 y 6), que se toma la información del último año disponible, 2021. Para más información sobre las contribuciones específicas e información relativa a las revistas, consultar los Anexos II y III.

3.1. Estudio 1

Calavia, M. B., Blanco, T., & Casas, R. (2021). Fostering creativity as a problem-solving competence through design: Think-Create-Learn, a tool for teachers. *Thinking skills and creativity, 39,* 100761. https://doi.org/10.1016/j.tsc.2020.100761

BD: JCR | FI: 3.652 | Q: *Education & Educational Research* (Q1 - 63/270)

Thinking Skills and Creativity 39 (2021) 100761

Contents lists available at ScienceDirect

Thinking Skills and Creativity

journal homepage: www.elsevier.com/locate/tsc

Fostering creativity as a problem-solving competence through design: Think-Create-Learn, a tool for teachers

M. Belén Calavia [a,b,d], Teresa Blanco [a,b,c,e,*], Roberto Casas [a,d]

[a] Howlab – Human Openware Research Group, Aragon Institute of Engineering Research (I3A), University of Zaragoza, Zaragoza, Spain
[b] Department of Design and Manufacturing Engineering, University of Zaragoza, Zaragoza, Spain
[c] Department of Musical, Plastic and Body Language Expression, University of Zaragoza, Zaragoza, Spain
[d] Department of Electronic Engineering, University of Zaragoza, Zaragoza, Spain
[e] Geospatium Lab. Zaragoza, Spain

ARTICLE INFO

Keywords:
Creativity
Design thinking
Didactics
Methodology
Teaching skills

ABSTRACT

Although there is no doubt about the relevance of creativity within education, theory has not been always translated into the practical level, for many reasons. In this paper we analyse the state of art, studying the methods through which creativity is understood and applied by teachers, and identifying problems and opportunities. Accordingly, we conducted a literature review to identify what should be considered to foster creativity in classrooms; from this review, we define fifteen key indicators of creativity in education: incorporation, practicality, novel, atmosphere, stimulation, analysis, cooperation, intrinsic motivation, participation, flexibility, uncertainty, time, divergence, self-evaluation, and redefinition. Based on these indicators, we provide a methodological proposal and a set of practical resources to help the teacher to encourage creativity in any classroom. 'Think-Create-Learn' relies on open, accessible, and intuitive design-based tools, facing challenges through a creative, problem-solving approach; connecting the contents with the student's interests and reality; and generating new competency learning possibilities. The assessment of the methodology, with teachers and students, demonstrates its positive integration into the lines of current teaching curriculums, its validity to support mentioned factors, and its ability to aid teachers to produce more creative people. In short, this paper evidences how design discipline and the methodology proposed could have a relevant role in the creativity development inside educational centres.

1. Introduction

Decades ago, Guilford (1950) wondered why the schools failed to produce 'more creative people' and, finally, creativity has been considered one of the most important 21 st century thinking skills (Ahmadi, Peter, Lubart, & Besançon, 2019; Collard & Looney, 2014; Guo & Woulfin, 2016; Henriksen, Mishra, & Fisser, 2016; Mishra & Mehta, 2017; Nakano & Wechsler, 2018). But do we really know how to develop and promote it? Has the theory been translated into the practical level?

Creativity is an essentially combinatorial process; it is the ability to connect learned knowledge to solve problems and create new things (Kleiman, 2008). Thus, it allows society to advance, looking beyond the established ways, answering to the changing world, and

* Corresponding author at: Howlab – Human Openware Research Group, Aragon Institute of Engineering Research (I3A), University of Zaragoza, C/Mariano Esquillor, s/n, 50018, Zaragoza, Spain.
E-mail address: tblanco@unizar.es (T. Blanco).

https://doi.org/10.1016/j.tsc.2020.100761
Received 24 April 2020; Received in revised form 3 October 2020; Accepted 15 November 2020
Available online 24 November 2020

increasing the quality of life (De Bono & Castillo, 1994; Hernández-Torrano & Ibrayeva, 2020; Spendlove, 2008). Creativity tends to be related to problem-solving because 'the two share many processes' (Reiter-Palmon & Illies, 2004). Although there is a debate about their exact relationship (Kirton, 2004; Parkhurst, 1999), there are authors that understand that creativity is promoted by problem-solving (Fasko, 2001; Feldhusen & Treffinger, 1985; Guilford, 1967; Khalid et al., 2020) and that requires a cognitive process away from luck or divine spark (Howard, Culley, & Dekoninck, 2008).

Our point of departure is that creativity is not a talent limited to some people but is present in all humans, to a greater or lesser extent (Collard & Looney, 2014; Guilford, 1950), and that to awake, stimulate, and develop this potential requires training in a favourable environment (Burkus, 2013; López, 2008). Obviously, the educational environment has a key role in this matter: people spend a lot of time there, and it reaches all kind of social classes (Chan & Yuen, 2014; Davies et al., 2013; Shaheen, 2010). In fact, for many, it should be transversally embedded within the whole curriculum of the educational programs (Daly, Mosyjowski, & Seifert, 2014; Fasko, 2001), being present in four pillars: educator, student, environment, and methodological resources (López, 2008). In this way, the learning environment could favour student's own development, boosting productivity, adaptability, and efficiency (Craft, 2003; Davies et al., 2013; Simonton, 2000).

It is true that a few years ago, a change in education policy began to spread throughout the world with the objective of combining creativity and knowledge as an engine of school improvement (Burnard, 2006; Collard & Looney, 2014; Dickhut, 2003). Creativity has transformed into one of the curriculum and pedagogy spotlights (Wilson, 2005) at several educational levels, from the early years to primary education for most countries and up to higher education, for some of them (Shaheen, 2010).

Unfortunately, although there is no doubt that interest in creativity within education has increased, in practice, it remains difficult to achieve, and it is often reduced as a separate area from other educational objectives (Spendlove, 2008). This is caused by barriers of widely varied natures, complex and difficult to address for educators (Henriksen, Richardson, & Mehta, 2017).

Perhaps one of the biggest problems is the strong prevalence of the traditional methods of teaching that still exist in formal education, both in public or private schools, and at all educational levels. Methodology is based on the student as a blank slate onto which information is etched by the teacher; on the use of conferences and passive learning, where students listen or watch how the instructor solves problems; and on the textbooks. Some factors that may influence the prevalence of traditional methodologies are the teacher profile (age, motivation/vocation, personal situation), as well as on the administrative structure of the educational centres — in terms of resources availability, restricted hours, class size, comfort, time constraints, and level of communication and joint work among teachers (Lee & Erdogan, 2007; McMullan, 2016; Nguyen et al., 2017; Qi, 2017; Zhang & Guo, 2017; Zhao & Meng, 2015).

Another important factor is that, as a knowledge area, creativity is a multifaceted, and a relatively new and unknown activity. As López (2008) highlighted, '*Creativity aims to promote the divergent in a converged environment; the indefinite in a system that aims to transmit the defined and known*', hence placing the educator in an uncertain position. Also, the term 'creativity' is sometimes used incorrectly; creativity and imagination are used interchangeably (Craft, 2002), and creativity is linked, by default, to arts or leisure (Henriksen et al., 2017; Seltzer & Bentley, 1999). Additionally, the term is surrounded by ingrained myths (Burkus, 2013; Cropley, 2016, 2018; MacLaren, 2012) oblivious to the idea of creativity as a process.

Considering this background, the need is clear for practical solutions that help teachers to encourage creativity in the classrooms. One of the knowledge areas that can have a very positive influence on this task is the design field, and Design Thinking in its broadest sense. Creativity and design are closely related, and many authors recognise Design Thinking, *per se*, as a creative process (Elwood, Savenye, Jordan, Larson, & Zapata, 2016; Henriksen et al., 2017; Hernández Leo, Agostinho, Beardsley, Bennet, & Lockyer, 2017; Jordan, 2016; Koehler & Mishra, 2005). Design thinking is an iterative process that repeatedly reformulates a problem to find its core and then analyses possible solutions to find the most favourable, allowing for the formation of 'creative bridges' between problems and solutions (Cross, 2011; Dorst & Cross, 2001). As Blanco (2016) stated, '*the approach from the design represents a differential advantage, both for the approach to the problem, and for the efficiency, affordability and adaptability of its tools*'. In this sense, Design Thinking achieves a balance between convergent and divergent processes, both of which are essential to develop transversal creative thinking skill (Elwood et al., 2016; Gu, Dijksterhuis, & Ritter, 2019; Hadar & Tirosh, 2019).

In the education field, Design Thinking can foster open-mindedness in students, create an effective framework to promote creativity as a transversal element (Mosely, Wright, & Wrigley, 2018; Page & Thorsteinsson, 2017; Thorsteinsson & Page, 2017), and improve skills such as collaboration, problem-solving, and innovation, among others (Brown, 2008; Razzouk & Shute, 2012). By developing these skills, the student can achieve what is known as 'creative confidence' (Rauth, Köppen, Jobst, & Meinel, 2010). Therefore, teachers should employ Design Thinking in their classrooms (Brown, 2008; Carroll et al., 2010; Lin, Shadiev, Hwang, & Shen, 2020; Lor, 2017; Razzouk & Shute, 2012; Retna, 2016).

For these reasons, the need to support educators with tools and approaches from the point of view of this discipline has been already detected (Elwood et al., 2016; Henriksen et al., 2017; Hernández Leo et al., 2017; Hoogveld, Paas, & Jochems, 2005; Jordan, 2016; Norton & Hathaway, 2015; Retna, 2016). In this sense, some initiatives have been launched; for example, Ideo (2013) provided some guidance for teachers to design certain solutions, but focused on the schools' facilities.

To address the problem, in the next sections of this paper, we present a methodology called Think-Create-Learn (TCL). Section 2 shows the theoretical bases, stressing the training of more creative individuals. Section 3 collects the results of TCL assessment, carried out in a real educational environment with end users (teachers and students of 15–16 years old), by qualitative and quantitative methods. Finally, Section 4 discusses TCL's utility, the advantages, difficulties, and limitations derived from its implementation, and the feedback necessary for its improvement.

2. Materials and methods

As explained in the introduction, in order to develop a resource that encourages creativity in the classroom, some challenges must be addressed, such as the frequent use of traditional educational methodologies, the education system limitations, and the interpretation of the term 'creativity'.

2.1. Theoretical bases

Evidently, developing a resource that fosters creativity is not a direct task, and its purpose must be based on a scientific approach. Therefore, the first step was to identify, as a theoretical basis, those factors which influence the development of creativity. To accomplish this, we conducted a literature search, in accordance to Lodico, Spaulding, and Voegtle (2010), employing ScienceDirect, Google Scholar, Libraries, and ERIC. We used the term 'creativity' in combination with the terms 'factors', 'aspects', 'evaluation', 'theory', 'education', 'teaching', and 'materials'. As inclusion criteria, we selected those publications that described creativity characteristics, how to introduce creativity in education, or how to teach creativity.

Under these criteria, from the title and the abstract, it was determined which studies met the inclusion criteria. In the selected publications, we identified ideas and concepts related to the creative process, which could be developed in the educational environment, and which defined key aspects for introducing and fostering creativity in classrooms. Despite not considering a specific field during the search, the authors of the selected publications turned out to be mostly from psychology and education fields. It is understandable, given the scope of the research, and also because we excluded those quotes that were directly related to other environments (e.g. business, industry). In any case, the fields of reviewed authors give an idea of the theoretical bases on which the determination of the factors is based. The next step in the process was based on taxonomic sorting method (Withers et al., 2014), specifically the open card sorting method (Spencer & Warfel, 2004). We wrote the selected quotes on sticky notes (cards) and placed them on a large blackboard. Then, we combined these cards to make conceptual and thematic groups, which were no pre-established. Finally, we named each group to describe the content. As a result, we isolated 15 thematic groups, which are the 15 creativity factors shown in Table 1. The factors were organised according to the hypothetical sequence of use of teaching resources, and we collated them with colleagues from design and education field.

Table 1
Creativity Factors.

Factor	Definition	References
1. Incorporation	It is adapted correctly to the curriculum	(Feldhusen & Treffinger, 1985; Finke, Ward, & Smith, 1992; Logan, Logan, & García, 1980; López, 2008; Şendurur, Ersoy, & Çetin, 2016; Sternberg & Lubart, 1997; Torre & Violant, 2006)
2. Practicality	The materials are logical, useful, and sensitive to the needs of the teacher and student	(Finke et al., 1992; López, 2008; Şendurur et al., 2016)
3. Novel	It is original and attractive	(Finke et al., 1992; Guilford, 1950; Huidobro & González, 2004; Şendurur et al., 2016; Simonton, 2000; Sternberg & Lubart, 1997; Torrance, 1972)
4. Atmosphere	It seeks to escape the monotonous, dogmatic, and traditional work	(Craft, 2003; Feldhusen & Treffinger, 1985; Gervilla, 2003; Lewis, 2009; Logan et al., 1980; López, 2008; Peterson, 2001)
5. Stimulation	It helps to awaken interest	(Craft, 2003; Feldhusen & Treffinger, 1985; Gervilla, 2003; González, 2006; Huidobro & González, 2004; Torre & Violant, 2006)
6. Analysis	The concepts are understood	(Hennessey & Amabile, 1987; Huidobro & González, 2004; Simonton, 2000)
7. Cooperation	It promotes communication and teamwork	(Amabile, 1998; Gervilla, 2003; Huidobro & González, 2004; Torre & Violant, 2006)
8. Intrinsic Motivation	Students are motivated in order to perform actions by themselves	(Amabile, 1998; Craft, 2003; González, 2006; Guilford, 1950; Huidobro & González, 2004; Logan et al., 1980; López, 2008; Simonton, 2000; Sternberg & Lubart, 1997; Torrance, 1972; Torre & Violant, 2006)
9. Participation	It encourages participation, welcoming opinions, questions, and answers	(Fasko, 2001; Feldhusen & Treffinger, 1985; Gervilla, 2003; González, 2006; Huidobro & González, 2004)
10. Flexibility	It allows changes or variations as required	(Finke et al., 1992; Gervilla, 2003; González, 2006; Guilford, 1950; Huidobro & González, 2004; Logan et al., 1980; Simonton, 2000; Sternberg & Lubart, 1997; Torrance, 1972; Torre & Violant, 2006)
11. Uncertainty	It fosters curiosity, inquiry, research, and experience and allows for making mistakes	(Fasko, 2001; Feldhusen & Treffinger, 1985; Gervilla, 2003; González, 2006; Guilford, 1950; Hennessey & Amabile, 1987; Huidobro & González, 2004; Lewis, 2009; Logan et al., 1980; Peterson, 2001; Simonton, 2000; Sternberg & Lubart, 1997; Torrance, 1972)
12. Time	It allows time for reflection	(Feldhusen & Treffinger, 1985)
13. Divergence	It allows for looking at things from different perspective to find more than one possible solution	(Feldhusen & Treffinger, 1985; González, 2006; Guilford, 1950; Huidobro & González, 2004; Simonton, 2000; Sternberg & Lubart, 1997)
14. Self-evaluation	It requires self-evaluation for reflection and enrichment	(Gervilla, 2003; Logan et al., 1980; Torre & Violant, 2006)
15. Redefinition	It requires the student to take feedback and redefine the problem/solution/etc.	(Gervilla, 2003; Guilford, 1950; Torrance, 1972)

2.2. Methodology rationale

Despite the advantages of Design Thinking for students' education, as happens with creativity, its application in the classroom is not a straightforward labour. Thus, TCL has three fundamental bases: the 15 creativity factors, the adaptation of Design Thinking models, and the development of didactic materials. Additionally, we designed the methodology based on our experience in design and didactics, as well as on a collaborative approach between both disciplines. During the development of TCL, we closely cooperated with teachers from different training cycles; they provided feedback on and a full perspective of the educational environment.

One of our first decisions was to order the phases of the methodology, which, as well as the factors, were organised from the general characteristics of didactic material to the specific impact of the material on the students. Fig. 1 details the relationship between TCL phases (identified with different colours) with the creativity factors enhanced in each of them.

The first and second phases are carried out individually by the teacher before the class; the first has a formative nature and the second an operative nature. The third phase constitutes the core of the action with the students in the classroom, and the fourth phase requires the student to reflect on their learning and allows for the dissemination of the results.

The development of each phase was formed to materialise one or more creativity factors (see Fig. 1). The first phase, 'Integrate', introduces the teacher to the theoretical basis of the methodology and identifies the initial creativity factors which are focused on adapting the materials into the environment. The second phase, 'Prepare', helps the teacher to set the operational resources. In this case, attention was given to provide enough flexibility to be adapted to each educator's needs. The third phase, 'Apply', implements the

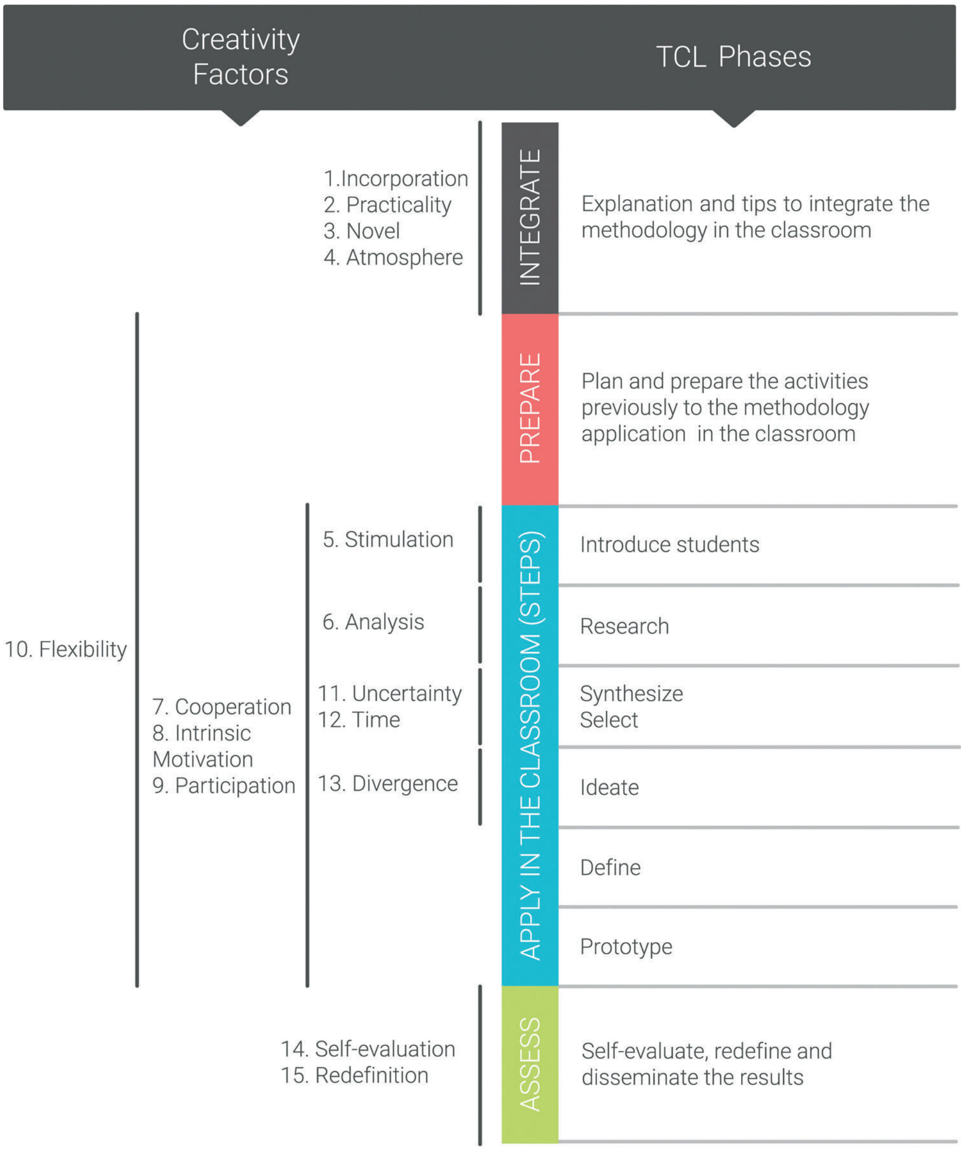


Fig. 1. Think-Create-Learn methodology.

material in the classroom and fosters the development of the factors by the students. The evolution of this phase and its steps was inspired by the Design Thinking model 'Double Diamond'; the first diamond involves exploring an issue widely or deeply (divergent thinking) and then focusing on a challenge (convergent thinking), and the second diamond involves giving different answers to the challenge (divergent thinking) and then defining the solution (convergent thinking) (Design Council, 2005). Finally, the fourth phase, 'Assess', evaluates learning after the methodology application and allows for the student to reflect on their new knowledge. In this manner, the methodology considers assessment as a key part of the learning process.

Overall, TCL aims to help teachers to apply Design Thinking in the classroom and is focused on transforming knowledge into solving challenges, all in order to foster creative ability in students and set new competency learning possibilities.

2.3. Methodology materials and methodology implementation

As mentioned in the introduction section, both the visual and the tactile nature of the materials are crucial in Design-Thinking processes. TCL is embodied in a practical kit (see Fig. 2) that consists of three material types: a manual to teach by challenges, complementary templates to fill and follow the steps, and other tangible support materials. Every resource has a careful, simple appearance, adapted to both teachers and students.

The manual consists of 22 guide cards which explain to the teacher step-by-step how to use TCL in the classroom. Fig. 3 shows a card example, where the structure and elements designed for consistency with the other materials are described.

The complementary templates are wide sheets that make application of theory possible (see supplementary files). Their main function is to save the teacher time in materials preparation and to optimise students' activities execution. They provide the added benefit of avoiding potential blocks caused by the fear of the blank page.

The support materials are tangible and colourful resources such as post-its, stickers, a stopwatch, markers, etc., aimed to facilitate students' work and to favour the activation of the right side of their brains.

Fig. 4 depicts the methodology steps and relates them to the specific materials. The first three columns describe the materials mentioned above. Additionally, the fourth column includes how TCL was applied and assessed in the real environment, as detailed in Section 2.4.

2.4. Assessment

TCL was designed and developed following an iterative process in which we situated two separated assessments with different objectives and strategies, following the Xassess evaluation methodology (Blanco, Berbegal, Blasco, & Casas, 2016). We selected Xassess because it is a validated evaluation method centred in multidisciplinary teams, that offered several advantages, e.g. it can be easily adapted to the context; considers the assessment from the initial stages of the project; merges qualitative and quantitative approaches; and includes the vision of all the disciplines involved in the project. Xassess poses three evaluation strategies: (1) 'complementation' (each product dimension is evaluated with one qualitative or quantitative technique), (2) 'triangulation' (each dimension is evaluated with two or more parallel techniques), and (3) 'combination' (each dimension is evaluated with two or more successive techniques). In this study, we followed strategies of both complementation and combination of mixed methods. Tables 2 and 3 illustrate the general and detailed overview of evaluation objectives, strategies, and dimensions. We conducted the assessment in accordance with relevant ethical guidelines (Lodico et al., 2010), providing a verbal explanation and obtaining written consent from the participants (parental consent was obtained for participants under 18 years old).

The first evaluation was carried out within the development process of TCL. We selected a sole but significant user, as an 'expert in the field' (in line with the User-Centred Design premises), who provided a triple vision: as a teacher, as a professional in teacher training, and as a proxy of other users, the students. The prototype (Fig. 2) was presented to the user by the evaluator, in a large room with a warm atmosphere. The user was asked to handle the TCL kit in order to raise a use case related to one of the subjects she was

Fig. 2. Very first kit's physical prototype developed to assess TCL.

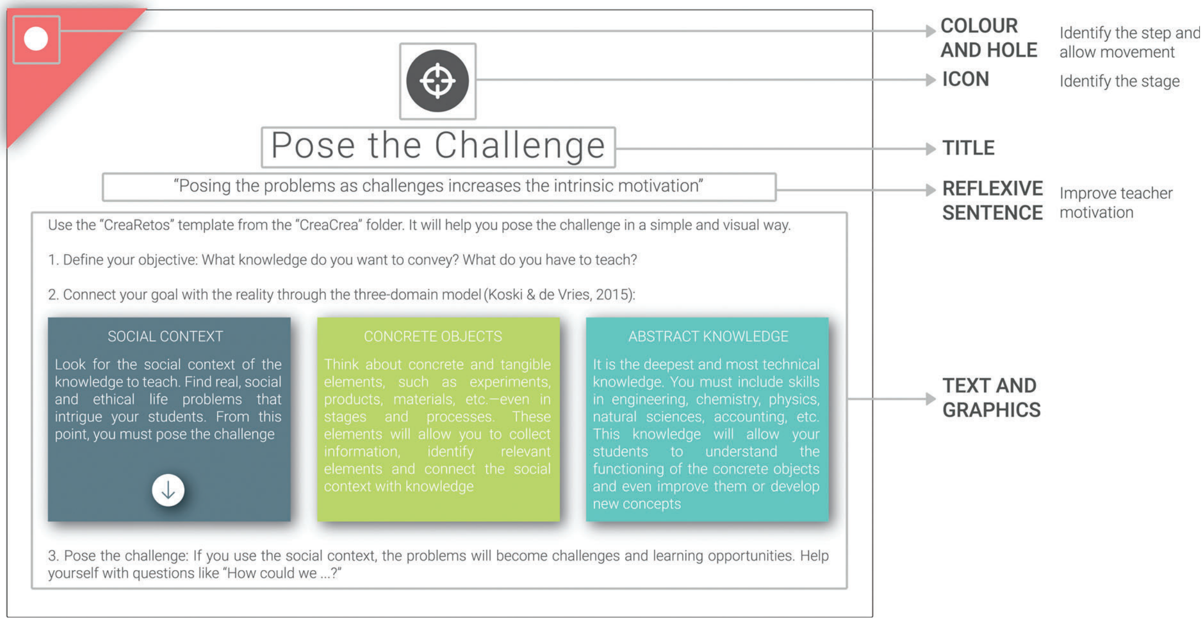


Fig. 3. Card elements.

teaching at the moment. She utilised the methodology kit, reviewing the theoretical bases and designing the educational activities for the classroom, while the evaluator observed in a non-intrusive manner. At the end, we discussed barriers and enablers in a semi-structured interview, placing a special emphasis on the TCL adequacy to curriculum objectives. We called this discussion the 'Theoretical curriculum review' (see Table 3).

After having redesigned the methodology from the mid-term evaluation results (see Section 3), the second evaluation took place in a real educational environment with end users (teachers and students). The framework was set in two classes (A and B) of a high school, with a total sample of 48 people: 46 students (each group consisted of 23 students) aged 15–16 years old, and two teachers with different profiles: main teacher (MT) and trainee teacher (TT). We considered teachers as the first level users because they interpret and apply the methodology, while the students represented the end user who benefits from the methodology implementation.

In the assessment procedure, TCL was mainly managed by the TT, less experienced, but having knowledge and sensitivity in new methodologies; the MT acted as supervisor, from his extensive experience in the centre and with students, and as quantitative evaluator of the students' achievement. Finally, a team of three technical evaluators conducted and assessed the whole process.

In this second evaluation, the TT used the TCL kit autonomously from the beginning, planning and determining the activities by himself, while the evaluators acted as a support team and observers. The TT read cards, completed templates, and selected the support material, considering restrictions regarding the subject topic, time, space, number of students, and students' skills. Subsequently, methodology was implemented in the classroom (see Fig. 4), being overseen by the TT.

Starting from the Blanco et al. (2016) theoretical assessment framework, we adapted our evaluation strategy to the idiosyncrasy of the education scenario, focusing on the collaborative analysis offered by the different perspectives (the external vision from the three technical evaluators specialised in engineering design; the fresh and involved vision from the TT; and the experienced and objective vision from the MT).

Table 3 shows how, why, and by whom each creativity factor was evaluated, including indicators, resources, and techniques applied during the experimentation, as well as the actors and scenarios involved. Although the phases were consecutive, the table assembles every dimension, regardless of whether they correspond to the first or second evaluation phase.

The techniques shown in Table 3 were chosen from those described in the literature (Lodico et al., 2010), in accordance with each of the 15 indicators, and were classified under two perspectives: teacher and student. Likewise, the selection of methods was based on the time available, the number of users, and the teachers' previous experience.

During application of the methodology in the classroom, the teachers (TT and MT) acted as evaluators in the field, conducting 'observation' and taking 'field notes' in a non-intrusive manner. To facilitate this process, a guide that included key concepts to be observed was provided to the teacher (TT). This guide had questions particularised for each activity, including: Has the class been interesting to the students? Have the students experienced difficulties? Have the students been involved? Have they collaborated as a team? Have they been motivated? How much time have they invested?

All these observations were shared in 'periodic internal discussions' between the teachers (TT and MT) and the three technical evaluators. In these discussions, the teachers acted as users, that is, as participants assessed by the technical evaluators. Overall, six periodic internal discussions of 40 min each were conducted. In each session, one of the technical evaluators guided the group and inquired about the specific indicators shown in Table 3. After each of these sessions, the three technical evaluators met to discuss the

Fig. 4. Scheme of steps, kit materials, and implementation.

conclusions obtained, which are considered in Section 3.

After the TCL application in class and to gain the teachers' perspectives, one of the technical evaluators conducted a 'semi-structured interview' with TT and MT, in which the voice was recorded. The interview included questions and comments such as: What perception do you have about design and creativity? How would you define the material used during the classes? How would you define students' attitudes during the classes? In order to avoid bias that evaluators may introduce, the formulation of the questions was carefully examined, trying not to affirm preconceptions of the researchers, and prevent the Hawthorne effect, that is, the tendency to the positive response of the interviewees due to the special treatment they receive from the evaluator (Adair, 1984; Diaper, 1990).The

Fig. 5. (a) Investigation/brainstorming; (b) information synthesis; (c) ideation and concepts.

Table 2
Evaluations and General Objectives.

	Mid-term Evaluation	Second Evaluation (after TCL redesign)
Objectives	The objective was to validate the initial methodology idea and clear design doubts in a controlled environment, in order to redesign a final version of TCL.	The objective was to validate the whole methodology in a real environment, with end users (both students and teachers) and no time constraints in material preparation.
Strategies	Qualitative methods in a complementary relationship (each TCL dimension was evaluated with an evaluation method).	Combinatorial strategy of mixed methods, qualitative and quantitative (each TCL dimension was evaluated with several evaluation methods that complement each other).

interviews were transcribed and coded according to the thematic analysis approach (Patton, 2014) and using the objectives shown in Table 2 as themes. The full transcriptions were sent to the teachers for review (Merriam, 1988) and were read several times separately by each of the three technical evaluators. Afterwards, the researchers discussed their reflections; in this discussion, the evaluators agreed to justify their suggestions with verbatims and to avoid inserting their judgments, directions or beliefs without data from the conducted research. Once a consensus was reached, the latent content and implicit messages of each theme were described in the results section.

Additionally, to gather students' experiences and opinions, we used several techniques. 'Survey' included several closed and open items and Likert scales to obtain perceptions on the assessment objectives. The survey included questions and comments such as: Have you found a difference with the materials used in other classes? Why? Have you felt motivated when solving the activities and challenges posed? Then, the students completed the self-assessment form, namely 'sheet CreaEvaluation'. Each student reflected and wrote about their work, the work of their team, and the work of another group. The self-assessments were coded by one of the technical evaluators, who grouped similar reflections. Additionally, we administered an exam. To analyse the students' knowledge acquisition, the teachers (MT and TT) discussed the results of the group work and the final exam. All these evaluation tools permitted us to extract the findings described in Section 3.

3. Results

The mid-term evaluation with the mentioned expert user was aimed to improve its quality before its application in the classroom and involved changes in TCL. The expert user stressed the importance of the writing to improve its adaptation to the educational environment, replacing design language for educational language – for example: 'Use "content" and "competence" instead of "objective". The teacher does not work with the "objective" but works with "content" or "competence"'. She emphasised the need to use direct language with clear instructions: 'Summarise paragraphs; write directly and in a more informal manner (…); use more icons to make the methodology more accessible. The end goal then, was to reword certain sentences and improve the graphic content. Specifically, some cards and templates were redesigned, since she commented that they could generate confusion or mistrust. For example, she wrote, 'In the planning template, I have to code and create the plan myself (…); however, the template should indicate how to achieve this task. Many teachers do not know what resources to use to plan their classes (…) they use a textbook, not because it is the best material, but because it is guided'. She also determined the need to include new templates: 'I propose to include an agreement sheet at the beginning. In my classes, students sign an agreement or contract to have a specific role. This contract increases their participation, assuming their responsibility'. Finally, she stressed the importance of paying more attention to some less-contemplated factors, such as 'redefinition': 'We are not ensuring that the teacher redefines. It seems obvious that the teacher reviews and provides feedback to the students, but believe me, it is not'. Therefore, feedback stickers were included so that the teacher could write comments and 'likes', and the students could annotate their doubts in situ.

Table 3
Objective, Indicators, and Evaluation Tools.

Creativity factors	Evaluation objective	Perspective	Indicator	Technique
1. Incorporation 10. Flexibility	Incorporation and adaptation to the environment and curriculum	Teachers	TCL adequacy to the curriculum objectives	Theoretical curriculum review, identifying proposed kit consistency
			Methodology's flexibility to be adapted to the topic	Observation and field notes (while teacher uses the tool);
			Difficulties detected when adapting it	Semi-structured interview
2. Practicality 3. Novel	Material suitability	Teachers	Teacher acceptance/perspectives about the methodology, manual, and resources.	Observation and field notes; Periodic internal discussions; Semi-structured interview
			Opinion about design techniques Interest in using the methodology	Semi-structured interview
			Analysis material usage by students	Observation and field notes; Periodic internal discussions
		Student	Student acceptance/perspectives about the methodology	Survey (closed question)
			Comparison to other materials used in classes	Survey (closed and open question)
4. Atmosphere 9. Participation	Warm atmosphere and participation	Teachers	Increased participation and communication, compared to other classes Dialogue between teacher-student, student-student, student-teacher Students' attitudes analysis	Observation and field notes; Periodic internal discussions; Semi-structured interview
		Student	Perception of how they felt during class	Survey (closed question)
			Opinion about the atmosphere	Survey (closed and open question)
			Perception about participation level	Survey (closed question)
			Participation level in the classroom compared to other classes	Survey (closed and open question)
5. Stimulation. 8. Intrinsic motivation 9. Participation	Students' motivation.	Teachers	Students' participation level, questions, opinions compared to other classes. Students' interest analysis in the classes Amount of information collected by students Comparison with other classes and previous works	Observation and field notes; Periodic internal discussions; Semi-structured interview
		Student	Interest aroused by classes Attitude and disposition Students' motivation to solve challenges and activities Related concepts with their lives	Survey (closed question)
6. Analysis 11. Uncertainty	Knowledge acquisition	Teachers	Students' level in Geology	Semi-structured interview
			Learning concepts different to memory	Observation and field notes; Periodic internal discussions
			Students' marks	Group work qualitative-quantitative evaluation
			Evolution of students' marks.	Final exam
		Student	Student perception about learning Geology	Observation and field notes; Periodic internal discussions
			Geology concepts understanding	Group work and final exam
7. Cooperation	Teamwork	Teachers	Communication, coordination, and commitment among the members	Semi-structured interview
			Team spirit	Observation and field notes; Periodic internal discussions
		Student	General opinion about teamwork	Survey (closed and open question)
			Opinion about own team (2 good aspects and 1 to improve) Opinion about other teams (2 good aspects and 1 to improve)	Sheet 'CreaEvaluation'
13. Divergence	Divergence	Teachers	Amount of students' ideas Ideas analysis Relation between ideas and the topic	Observation and field notes; Periodic internal discussions; Semi-structured interview
		Student	Students' perception about the quality of ideas	Sheet 'CreaEvaluation'
12. Time	Think time	Teachers	Relationship between reflection time and work	Semi-structured interview
14. Self–evaluation 15. Redefinition	Self–evaluation and redefinition	Teachers	Teachers' feedback (likes, comments, etc.) quality and quantity	Observation and field notes; Periodic internal discussions; Semi-structured interview
		Student		Sheet 'CreaEvaluation'

(*continued on next page*)

Table 3 (*continued*)

Creativity factors	Evaluation objective	Perspective	Indicator	Technique
	General opinion about methodology	Teachers	Opinion about own work within the team (2 good aspects and 1 to improve). General opinion about classes and methodology	Semi-structured interview
			Suggestions to improve the methodology	Semi-structured interview
		Student	Use of the methodology in other subjects Know what they liked most and least	Survey (open question)

The collaborative analysis (between the three technical evaluators and the teachers) of all the evaluation layers, mid-term evaluation and second evaluation, gave rise to the results shown in Table 4, presented in sections corresponding to the evaluation objectives collected in Table 3.

4. Discussion

The results show that the proposed methodology and materials for its implementation achieve their objectives and contemplate the 15 creativity factors of Table 1. It can be asserted that applying the methodology in the classroom has advantages for students and teachers: it boosts competence learning, fosters research and participation, facilitates putting knowledge learned into effect, and allows for knowing new techniques. Therefore, the experience validates the methodology's utility in the schools.

To frame the value of our results, it is interesting to analyse how other tools achieve the creativity factors in comparison to TCL. To accomplish this, we collected a total of eight representative tools from the educational field. We selected tools that 1) have a pedagogical basis similar to TCL; 2) seek learning through a different process than copying, memorisation, or reproduction; 3) are straightforward and easily adaptable; and 4) are easily accessible. The selected tools were presented to the three technical evaluators; individually, they reviewed each material and rated how each tool achieved the creativity factors. The authors then shared and discussed their assessments. By consensus, they determined to value each tool using a colour code in three levels: the resource considers the factor clearly (green), the resource considers the factor slightly (yellow), and the resource does not consider the factor (red). The indicators were reduced only to these three levels with the aim to ensure objectivity, assessing what could be observed in the available material of each proposal.

In this manner, Fig. 4 shows the extent to which TCL and the other representative resources satisfy each creativity factor. As mentioned, each factor is associated with a number according to the hypothetical sequence of use of these resource types in class. The comparison allows us to display which stages are most and least represented.

As shown in Fig. 6, the first half of factors is considered in the majority of cases. This seems logical, since they are key premises to apply this resource type in the classroom, related to the adaptation to the curriculum, the material characteristics, and the break of monotony. However, the factors related to the use of tools in the classroom and with the specific contributions to the students are less considered. Although they are fundamental for creativity promotion, the participation, divergence, and uncertainty factors are not worked enough; and self-evaluation, key in reflection and enrichment, is not entirely considered in any of the cases. It should to be noted that Challenge-Based Learning (CBL) (Apple, 2011) has a lot in common with our proposal, meeting almost all factors. However, CBL lacks one of the essential bases in any educational material, which is practicality. It is true that CBL has a theoretical base more extensive and profound than other tools; however, it lacks the materials that favour and simplify its direct application in the classroom, such as kits, templates, complementary objects, and the like.

In TCL, all detected factors were kept in mind from its inception, but in the evaluation process, aspects to improve were detected (yellow squares in Fig. 4). The assessment process, conducted from the method Xassess, allowed the evaluation from the beginning of the project, as well as the collaborative assessment between different disciplines. Applying Xassess supposed a multidisciplinary challenge at all levels, considering teachers as users and also as members of the team, thus co-designers. This permitted the drawing of deep and structured conclusions, giving rise to key contributions at a methodological level. These are presented below organised upon the assessment objectives; some of them can be useful to improve the methodology; others can allow for the creation of new resources and new teaching methods to improve students' creativity.

4.1. Incorporation and adaptation to the environment and curriculum

To guarantee its feasibility in the classroom, any educational resource should start from these two premises. According to Blanco et al. (2016), the x-disciplinary perspective to which we attended favoured the factors' compliance and allowed us to adapt the methodology to the real environment. The results evidence it, both in the teachers' views and in the students' marks. It is also important to highlight the value of TCL in the more and more relevant competencies-based educational approach (Blanco, López-Forniés, & Zarazaga-Soria, 2017) and its weight for students' future employment and role in society (Tuning, 2003): it broadens the scope of normally addressed competencies and enhances students' soft skills. However, it is undeniable that to use this methodology requires an extra effort on the part of the teachers. They must consider: first, the preparation of the materials, since the teacher should understand and plan the methodology; then, the development of classes, where the teacher is in an unknown situation; and finally, the assessment of the results, about which the expert user commented, *'Evaluating the transversal competences of each student is*

Table 4
Assessment Results.

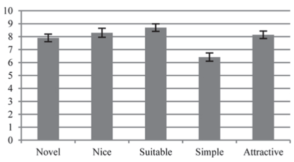
Objective	Teachers perspective	Students perspective
Material Suitability	Material quality was considered by teachers as a key element for the success of the tool. They claimed the materials were suitable. They valued positively the design discipline importance for materials development: *'This material increases student curiosity and participation. (…) the results would not have been the same. Things are not only what you say, but how you say them'* (TT). In addition, the MT confirmed, *'The material employed has been key, and students noticed the difference with respect to the materials of other classes'*. However, when teachers used the methodology materials, they detected the possibility of including previous teacher training: *'The guide templates are great and very important, but I think that previous training on design and methodology would be beneficial'* (expert user).	Students valued the methodology very positively, although 'simple' is the factor they punctuated as the lowest (Table 5), and they judged the methodology as demanding. Most (85.2%) considered there to be a difference with the materials used in other classes. *'It is more didactic, innovative, and practical than others. We are not used to work like that'*.
Warm Atmosphere and Participation	Both teachers considered that the atmosphere during the lessons was pleasant thanks to the activities, fostering the good attitude of students: *'Participation has been much more favourable and frequent than normal'* (MT). This was reflected in most of the sessions. For example, during the brainstorming (Fig. 5a) participation was very high in both classes. The students were comfortable and used informal assertions, opinions, and drawings: *'It would not be cool to be there when it (the natural catastrophe) happened',* talking about geology concepts. Both teachers were surprised: while they expected noise and disturbance, students were calm, respected their classmates, and payed attention to everyone.	The majority of students (81.5 %) confirmed they had participated more than usual. *'It wasn't a normal class, so we were more open to participate. Everybody has participated in everything'*. This was confirmed by the statistics (with an average score of 7.4 in the participation level of each student, and an 8 in the classmates' participation level) and by the teachers' testimony. All students confirmed the suitability of the learning atmosphere. 'Comfortable' is the most used adjective, followed by 'satisfied' and 'motivated'. The three main factors detected by them were: the teamwork, the activity's nature (enjoyable and entertaining), and the teachers' work and attitude. *'I really liked such a different way of teaching, your closeness, and how you valued our work. Thank you'*.
Students' Motivation and Interest for the subject	Both teachers agreed that motivation of students was constant throughout the sessions. The MT stressed the improvement over other classes. Among other examples, during the first session (Fig. 5a), *'Their questions evidence that they find* [the material] *stimulating (…) since the Geology subject is not usually very attractive'* (MT); in the second session (Fig. 5b), *'They synthesised the information with mind maps, speaking, drawing, using attractive materials'*; in the fifth session (Fig. 5c), *'When they used the 6−3-5 methodology, they were very focused and interested'* (TT). A clear indicator is the interest shown outside the classroom. TT stressed, *'Even during the weekend, students worked and shared information on Drive'*. Likewise, he met casually with a group of students attending an outside event related to geology; he added, '*This was really striking*'.	81.5 % of students declared they felt more motivated than in other classes: *'I liked the enthusiasm and the effort I had in doing the activities'*. This agrees with the teachers' observations. In the survey, they were asked to describe their mood before the class started; most chose 'happy' (48 %), followed by 'entertained' (22 %) and 'bored' (15 %). During the class, 63 % affirmed to be 'entertained', followed by 'glad' (15 %) and 'motivated' (11 %); when the class finished, most of the students admitted to being 'happy' (48 %), followed by 'motivated' (19 %) and 'glad' (15 %). It should be pointed out that two students chose 'bored' for all times, although they admitted being more motivated than in other classes. Also in accordance with teachers' observations, 44.4 % of students affirmed that these sessions made the geology topic more interesting for them, and 51.2 % found the subject related with some issues of their life. *'We have worked more dynamically in a boring subject, and now I see it as more interesting'*.
Knowledge acquisition	Results were good, but higher in Group A. For both teachers, the concepts were successfully understood, with a low failure rate (40 pass *vs* 6 fail) on the exam, while in the group work, all students passed (Table 6).	The qualitative results improve the statistic if we look at some of the students' reflections: - A different learning has been achieved: *'I have learned without studying too long with books;* [I learned the subject] *simply with research and listening'*. - Students' autonomy has been improved: *'I liked researching because I discovered data* [and] *curiosities…'*.
Teamwork	Both teachers detected differences between the groups. In Group A, all members worked adequately and equitably, while in Group B, not all students worked equally. Although the MT's opinion was, *'Students find it hard to organise teamwork; they are somehow inefficient',* he also highlighted that they had worked better than in other activities: *'Their work has been better than I expected since the motivation here has been higher'*.	Most students (85.2 %) also noticed a difference as a group and reflected upon the benefits obtained thanks to the interaction with their classmates*: 'It is better than working alone because we all learn from each other' and 'My team has provided me knowledge and positive personal experiences'*. In addition, they recognised their commitment with the group, since the rest of the members depended on their work: *'My role as coordinator was essential to carry out the work'*. However, some students reported that not all classmates worked equally: '*I would like if all students were involved equally in all activities*'; this coincides with the teachers' perspective.
Divergence	The TT observed that students were restricted: *'They are guided day-to-day, and when they do something different, they find it hard to be proactive and creative'*. Equally, the TT added, *'The ideas that they chose to develop weren't the most amazing'*. The TT observed three reasons to justify this choice: greater ease, fear of failure, and less social influence in students who proposed it.	Students noted the importance of divergent thinking: *'It allows me to think more and differently about something'*. They also noted the importance of putting knowledge learned into effect: '[It is necessary] *not only to study but to put knowledge into effect and provide a solution (moderately possible) to a current problem'*. Solutions proposed were very diverse (Fig. 5c): designing smart buildings and objects; ideas to stop the convection currents;

(*continued on next page*)

Table 4 (*continued*)

Objective	Teachers perspective	Students perspective
		research about the internal structure or traveling to the centre of the earth; and educational programs about emergencies were some of them.
Time constraints	The (short) times and the quickness of the activities were not a problem for the teachers. *'The stopwatch use has been very satisfactory; despite* [the limited] *time set, all students have finished the challenge since they have organised and adapted to the time proposed'* (TT).	Students offered two different stances: - There was a perception of lack of time for evaluated activities: 'I would like to have more classes to make the presentation better and to summarise the test content'. - When they do not associate their work with a mark, they sense the quickness as beneficial: 'I liked having little time because it was spontaneous, and the classes weren't long or boring; I was very focused'.
Self-evaluation	There was a special emphasis on the need for clear, dynamic, and interactive presentations: *'There was very little fluency in the oral presentation; several students needed to read a sheet'* (TT).	Among the students, the perception of the need for improvement regarding their oral skills was also common: *'I would like to explain better, more easily, and without shame. I am not good at presenting'*. Some of them criticised the presentations when evaluating other groups: *'I would have liked to see clearer presentations with better explanations from my classmates'*.
General Opinion about Methodology	Both teachers agreed that the methodology is interesting, and they would like to use it in their classes to get students more involved. *'My opinion is tremendously positive (…) the task (.) is achieved very broadly. In addition, despite being applied to an unpopular topic, very good results have been achieved'* (TT). However, MT commented, *'Maybe it is insufficient to assimilate all the contents of the subject'*. The expert user assured *'It is a demanding methodology for the student, since they must be fully active; thus, its use must be limited'*.	96 % of students affirmed they would like to use this methodology in other classes: *'I wish we had the opportunity to work with this methodology, at least once a quarter'*. Even those initially sceptical recognised the validity of the method: *'I was afraid of the test because the class was practical, but in the end (…) I learned the theory better'*. However, a student noted the lack of traditional classes: *'I would like to have had theoretical classes to take notes and specify the content for the exam (…) [because] the activity was more general than the exam, which was more specific'*.

Table 5
Survey Results for the Question Related to 'Material valuation'; Likert Scale from 0-10.



Average results. 95 % Confidence interval.

Table 6
Student Qualification Results (0-10).

	Group Work	Test	Final Mark
Group A	9.3 ± 0.5	7.9 ± 1.3	8.7 ±0.8
Group B	8.1 ±0.8	5.4 ± 2	7 ± 1.1

not a direct task; it proves a challenge'. Likewise, the difficulty of complying in time and scope with the curriculum, as well as the lack of specific training, could make the application of this methodology difficult. To face this challenge, we are now working on specific material to train and involve the teacher in the use of TCL, which will contribute also to the teacher's professional development.

4.2. *Material suitability*

Design influence on methodology and materials was found relevant and positive. One of the main objectives of Design Thinking and design development processes is to adapt the materials both to the context and to the different users, adding connotative and denotative value. Students' cumulative opinion about the material was positive, although it should be noted that some students did not describe it as a simple process *'some activities were really laborious'*. This is understandable, considering that the student must be fully active and participative, far from the passive stance adopted in the traditional methodology (Lee & Erdogan, 2007; McMullan, 2016; Nguyen et al., 2017; Qi, 2017; Zhang & Guo, 2017; Zhao & Meng, 2015) to which they were habituated. Thus, as well as for teachers, TCL constitutes a demanding methodology which requires an extra effort on the part of students, but it also offers them important advantages. Despite these benefits, as the expert user commented, *'TCL usage should be limited'*. On another level, it should be considered that, nowadays, new technologies offer stimulating possibilities to create and share ideas and content (Henriksen et al., 2016; Lombardi, 2007) and link well to the students' and teachers' reality. This idea was supported by the TT, who asked, *'Have you*

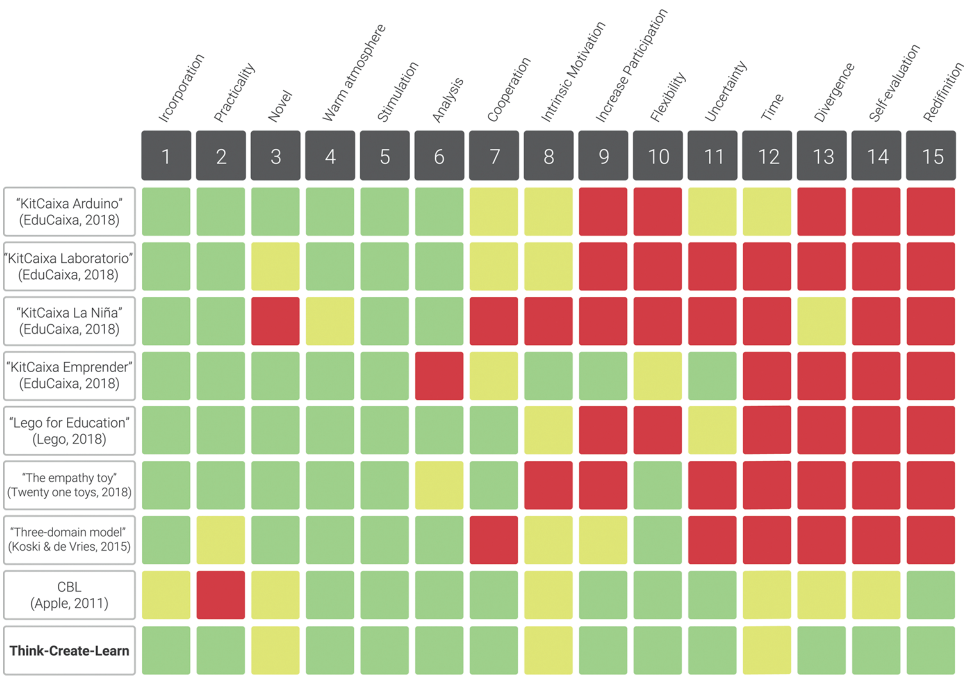


Fig. 6. Material analysis according to the creativity factors (EduCaixa (2018); Koski and de Vries (2015); Lego (2018) and Twenty one toys (2018)).

considered the digital option? A teacher could do this with a tablet'. It suggests that technology inclusion could make a difference in the methodology materialisation, which would be a significant improvement.

4.3. Warm atmosphere and participation

In TCL, one of the teachers' tasks is to bridge the division between teacher and students, so that the students relax and get involved in the activities in an uninhibited way. The methodology endeavoured to establish a comfortable climate based on trust and communication between teacher-student and student-student by different means: students and teachers used the material as a communication tool; the teacher was also asked to motivate the students with certain messages ('nothing is wrong', for example) and attitudes. And this type of relationship and dialogue brings significant benefits to students; as different authors assert, an adequate psychosocial environment boosts a didactic environment that promotes and encourages students to interact and participate with opinions, questions, and answers, increasing their academic learning (Thapa, Cohen, Guffey, & Higgins-D'Alessandro, 2013; Vass, 2017; Voelkl, 1995), and offering identity, security, familiarity, autonomy, and liberty (Thapa et al., 2013; Voelkl, 1995). Nevertheless, the atmosphere is affected by the duration of the sessions: *'Creating the right climate takes extra time and effort (…); when it is achieved, it is a pity to stop the class'*. Additionally, it is significant that the experience made the students appreciate the teachers' work, as seen in the students' comments. Therefore, we can affirm that, to some extent, the image of the teachers is improved, and the respect between students and teachers is fostered. This is a relevant point because one of the most repeated conflicts in society is that teachers are sometimes devalued in their work (Fort & Plaza, 2015).

4.4. Students' motivation

The results also evidence a high student motivation and interest during the activities. TCL permits a proactive learning environment, fostering investigation and experimentation, and showing that posing problems as challenges increases the students' intrinsic motivation, in line with López (2008) and Amabile (1998). This even leads them to quench their curiosity outside the classroom, which is significant. However, in several moments, it can be observed how students are concentrated on their own marks (test and presentations): *'How will the exam be?'*. Thus, with this reflection in mind, we consider that the intrinsic motivation factor is 'slightly' fulfilled in our methodology (see Fig. 6). This is a logical response to the established system; we cannot run away from the whole reality, but, of course, we align with Sternberg and Lubart (1997) and others about the necessity of devaluing the importance of marks as the first extrinsic motivator.

4.5. Knowledge acquisition

Also related to motivation, the methodology generated curiosity and attention for its materialisation and because students worked differently than in other classes. These coincide with the first two steps of the Neuroeducation sequence (Fig. 7) (Acaso, 2017). The

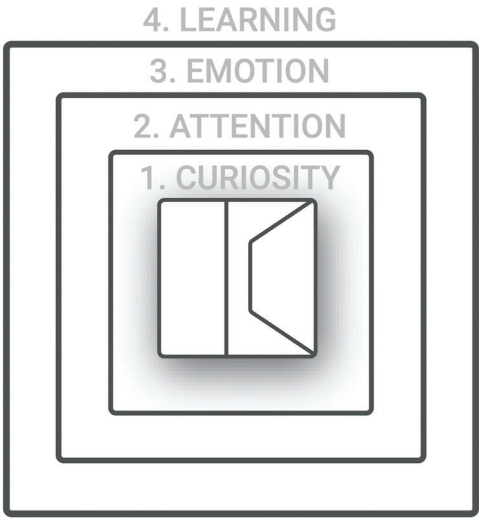


Fig. 7. Learning process according to Neuroeducation, adapted from Acaso (2017).

emotion came when the theory was linked to the real world. According to Gerver (2017), '*Great teachers have the ability to connect the concepts with the students' lives. And when students care about things, they learn them*'. We must not forget that the novelty of the material can play in our favour, but the design of the methodology allows us to totally refresh the stimuli from one project or subject to another. Additionally, the 'peer learning' (Topping, 2005) process is also evidenced since other teams' presentations are perceived as a source of learning and skills acquisition. Students learn from their classmates, seeing the different approaches and solutions that other groups have found for the same issue.

4.6. *Teamwork*

Teamwork is considered one of the key skills to access the professional world (Daly, Adams, & Bodner, 2012; Tulsi & Poonia, 2015; Valero, 2018). We formed groups of four or five in accordance with Fowler (1990) and Blanco et al. (2017), and we corroborated that it is an ideal number since they were manageable groups where everyone was able to contribute, and in general, the opinions were positive. The positive influence of the peer learning effect was achieved not only between groups but also inside the groups' members, as we can see in the comments. However, the teacher should be alert to help students work as a team, in terms of effectiveness, organisation, and bad attitude prevention; for example, those students that take advantage of teamwork to avoid tasks: *'During the investigation, a classmate did not search for information'*. Maybe it would be useful to include a guide in the methodology for teaching students how to work in teams in terms of commitment (to carry out the tasks), communication (to listen to different opinions), complementarity (to put things in common), coordination (to reach agreements), and trust (to express their own ideas).

4.7. *Divergence*

TCL contributes to fostering the divergent thinking drawn from uncertainty, risk-taking, and making mistakes, in line with Craft (2003). The teacher has an important role here as the resources provider and director; in this sense, TCL provides him or her the opportunity to train students on managing materials, tools, concepts, ideas, and structures, in line with what Feldhusen and Treffinger (1985) and Gervilla (2003) claim. In the experience, we included some rules related to the methods included in TCL; for example in brainstorming (avoid judgment and criticism, build on the others' thoughts, address only a conversation at a time, note all ideas, use simple sketches, etc.). However, we observed that, in some ways, the lack of practice restricted students, so allowing them to make decisions for themselves was a major challenge. In this regard, TT remarked, *'They constantly wanted my approval, despite the freedom offered during classes'*. The conclusions drawn from the teachers were very enlightening: greater ease, fear of failure, and the social influence of certain students could all play a limiting role. For these reasons, it can be said that TCL considers the divergence factor slightly (see Fig. 6).

4.8. *Time and self-evaluation*

TCL provides times in which the student evaluates his/her progress and performance, in order to promote reflection about what they has learned. The most repeated thought raised by the students themselves (and validated by teachers) is about the need for resources and training to carry out an effective public presentation, another soft skill that is usually missing; *'I get very nervous when I speak in public'*. Although the methodology contributes to practicing presentations and to speaking in public, it does not include materials focused on learning this skill. Thus, in future versions of TCL, it would be interesting to add resources to help in this competence formation. Additionally, it is interesting to observe the double standards in some students' perception, which unfortunately have to do with traditional systems based on extrinsic motivators. In particular is the case of the times assigned to each task, perceived as insufficient or sufficient depending on whether the student perceived this as related or not with a quantitative mark, sensing the evaluation separate from learning. This is, of course, a tough matter, but we believe that the adoption of methods such as the proposed could contribute to mitigate this phenomenon.

Some limitations need to be acknowledged, and further work needs to be conducted to address them. First, the scope of this study is confined only to a small sample of high school students in a Geology class, and the outcomes may not be fully generalisable to other disciplines and/or a broader population. Second, it should be noted that the research techniques used are mostly qualitative. In this type of research, the participants rely on their individual experience, memories, and expectations, which prevents the study from achieving total objectivity, complete neutrality, and biases the research to some extent (Ponterotto, 2005). Nonetheless, to minimise this effect and provide greater credibility, as commented before, we assessed each indicator with different methods. Third, the TCL application requires an extra effort on the part of the teacher, since they should act as a coach, a provider of resources, and a designer, facing complex and varied challenges. Therefore, the teacher needs to be familiar with new methodologies and Design Thinking or needs to be trained in some of these areas. Fourth, in the same manner, TCL is a demanding methodology for the student, since they must be fully active. Thus, the students' workload should be well-balanced, since an overload could be detrimental for their learning and their perception of active methodologies. In this regard, in order to enrich the students' experience and learning, further, and more ambitious, research could be conducted, with longer sessions and more detailed activities. Finally, it should be noted that the participants of this study were used to traditional methodology, such that understanding and developing the concepts about design and creativity as problem-solving was a complex task. Design and creativity introduce mess, divergence, and novelty in a defined, convergent, and traditional environment. Thus, understanding and developing design and creativity cannot be solved solely with the use of the proposed methodology, but TCL can be considered an aid to introduce these concepts.

5. Conclusions

In this paper, we proposed the Think-Create-Learn (TCL) methodology aimed at fostering creativity in the class through design. During the development of this methodology, we also contributed to the identification of 15 factors to be considered in the creation of new resources that foster creativity as a problem-solving skill. Thus, TCL is based on two pillars: the design thinking processes and these 15 factors.

In TCL, theory and practicality are balanced. It is embodied in a practical kit with several types of resources. A manual of 22 guide cards explains to the teacher step-by-step how to use TCL in the classroom. The templates make application of TCL theory easier, offering tools flexible enough to be adapted to any subject and helping the teacher to manage uncertainty. Both the visual and the tactile nature of every support material are crucial and contribute to the success of the tool.

TCL was assessed quantitatively and qualitatively in a real educational context with teachers and students. The results of this assessment showed that the proposed methodology contemplated all the key factors to enhance creativity, supporting the teacher's work, and fostering students' competency-based learning. Thus, we can affirm that this methodology provides a good tool to aid scholars, teachers, even designers to develop design and creativity.

This study also reflects the potential of applying Design Thinking in education. Design and creativity are multidimensional and difficult to teach, so further studies are needed to support teachers in this task. In this paper, we contribute to reaffirm (a) the need to create new resources for the development of creativity in educational centres, (b) the relevant role that the design discipline could have, and (c) the relevance of the 15 creativity factors to assess new proposal's effectiveness. Research in these directions would enhance students' 21 st century thinking skills.

Funding

This work was partially supported by the Government of Aragon, under Grant BOA20180615027, and under Grant T27_17R; and by the Spanish MINECO under Grant PTQ2018-010045.

CRediT authorship contribution statement

M. Belén Calavia: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Visualization, Funding acquisition. **Teresa Blanco:** Conceptualization, Methodology, Resources, Formal analysis, Writing - review & editing, Writing - original draft, Supervision, Funding acquisition. **Roberto Casas:** Conceptualization, Resources, Writing - review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgements

We would like to thank the teachers and students who participated in this study: this project would not have been possible without their participation and their feedback. Finally, we would like to thank the Government of Aragon and the Spanish MINECO for the financial support.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.tsc.2020.100761.

References

Acaso, M. (2017). Del design thinking al art thinking: las artes como metodología para cualquier asignatura. September 22 *Paper presented at the I international congress of educational innovation*.

Adair, J. G. (1984). The hawthorne effect: A reconsideration of the methodological artifact. *The Journal of Applied Psychology, 69*(2), 334.

Ahmadi, N., Peter, L., Lubart, T., & Besançon, M. (2019). School environments: Friend or foe for creativity education and research?. *Creativity under duress in education?* (pp. 255–266). Springer.

Amabile, T. M. (1998). *How to kill creativity*. Harvard Business School Publishing.

Apple. (2011). *Challenge based learning (CBL)*. https://images.apple.com/education/docs/CBL_Classroom_Guide_Jan_2011.pdf.

Blanco, T. (2016). *Metodologías de diseño como plataforma para la x-disciplinaridad en proyectos tecnológicos: Surfing disciplines (Doctoral dissertation)*. Retrieved from. Valencia, Spain: Universitat Politècnica de València https://riunet.upv.es/handle/10251/77149?show=full.

Blanco, T., Berbegal, A., Blasco, R., & Casas, R. (2016). Xassess: Crossdisciplinary framework in user-centred design of assistive products. *Journal of Engineering Design, 27*(9), 636–664.

Blanco, T., López-Forniés, I., & Zarazaga-Soria, F. J. (2017). Deconstructing the tower of babel: A design method to improve empathy and teamwork competences of informatics students. *International Journal of Technology and Design Education, 27*(2), 307–328.

Brown, T. (2008). Design thinking. *Harvard Business Review, 86*(6), 84.

Burkus, D. (2013). *The myths of creativity: The truth about how innovative companies and people generate great ideas*. John Wiley & Sons.

Burnard, P. (2006). Reflecting on the creativity agenda in education. *Cambridge Journal of Education, 36*(3), 313–318.

Carroll, M., Goldman, S., Britos, L., Koh, J., Royalty, A., & Hornstein, M. (2010). Destination, imagination and the fires within: Design thinking in a middle school classroom. *International Journal of Art & Design Education, 29*(1), 37–53.

Chan, S., & Yuen, M. (2014). Personal and environmental factors affecting teachers' creativity-fostering practices in Hong Kong. *Thinking Skills and Creativity, 12*, 69–77.

Collard, P., & Looney, J. (2014). Nurturing creativity in education. *European Journal of Education, 49*(3), 348–364.

Craft, A. (2002). *Creativity in the early years: A lifewide foundation*. A&C Black.

Craft, A. (2003). The limits to creativity in education: Dilemmas for the educator. *British Journal of Educational Studies, 51*(2), 113–127.

Cropley, A. (2016). The myths of heaven-sent creativity: Toward a perhaps less democratic but more down-to-earth understanding. *Creativity Research Journal, 28*(3), 238–246.

Cropley, A. (2018). The creativity-facilitating teacher index: Early thinking, and some recent reflections. *Creativity Fostering Teacher Behavior: Measurement and Research, 1*.

Cross, N. (2011). *Design thinking: Understanding how designers think and work*. Berg.

Daly, S. R., Adams, R. S., & Bodner, G. M. (2012). What does it mean to design? A qualitative investigation of design professionals' experiences. *Journal of Engineering Education, 101*(2), 187–219.

Daly, S. R., Mosyjowski, E. A., & Seifert, C. M. (2014). Teaching creativity in engineering courses. *Journal of Engineering Education, 103*(3), 417–449.

Davies, D., Jindal-Snape, D., Collier, C., Digby, R., Hay, P., & Howe, A. (2013). Creative learning environments in education. A systematic literature review. *Thinking Skills and Creativity, 8*, 80–91.

De Bono, E., & Castillo, O. (1994). *El pensamiento creativo*. Editorial Paidós.

Design Council. (2005). *The 'double diamond' design process model* Accessed 1 July 2020 https://www.designcouncil.org.uk/news-opinion/what-framework-innovation-design-councils-evolved-double-diamond.

Diaper, G. (1990). The hawthorne effect: A fresh examination. *Educational Studies, 16*(3), 261–267.

Dickhut, J. E. (2003). *A brief review of creativity*. Retrieved from http://www.personalityresearch.org/papers/dickhut.html.

Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problema-solution. *Design Studies, 22*(5), 425–437.

EduCaixa. (2018). *Educational platform* Accessed 15 December 2018 https://www.educaixa.com/es/home.

Elwood, K., Savenye, W., Jordan, M. E., Larson, J., & Zapata, C. (2016). Design thinking: A new construct for educators. *Paper session presented at the annual convention of the association of educational communications and technology*.

Fasko, D. (2001). Education and creativity. *Creativity Research Journal, 13*(3-4), 317–327.

Feldhusen, J. F., & Treffinger, D. J. (1985). *Creative thinking and problem solving in gifted education*. Dubuque, IO: Kendall/Hunt Publishing Company.

Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative cognition: Theory, research, and applications*. MIT Press.

Fort, J. T., & Plaza, Y. M. (2015). Malestar en la escuela. Conflictos entre profesores. *Educar, 51*(1), 169–188.

Fowler, T. C. (1990). *Value analysis in design*. CRC Press.

Gerver, R. (2017). Crear hoy la escuela del mañana: El futuro de la educación. September 22 *Paper presented at the I international congress of educational innovation*.

Gervilla, A. (2003). Creatividad aplicada. *Una Apuesta De Futuro* (p. 1).

González, C. A. (2006). Evaluación de la creatividad: más allá de una operatoria funcional. *Comprender Y Evaluar La Creatividad, 2*, 25–45.

Gu, X., Dijksterhuis, A., & Ritter, S. M. (2019). Fostering children's creative thinking skills with the 5-I training program. *Thinking Skills and Creativity, 32*, 92–101.

Guilford, J. P. (1950). Creativity. *American Psychologist, 5*(9), 444–454.

Guilford, J. P. (1967). Creativity: Yesterday, today and tomorrow. *The Journal of Creative Behavior, 1*(1), 3–14.

Guo, J., & Woulfin, S. (2016). Twenty-first century creativity: An investigation of how the partnership for 21st century instructional framework reflects the principles of creativity. *Roeper Review, 38*(3), 153–161.

Hadar, L. L., & Tirosh, M. (2019). Creative thinking in mathematics curriculum: An analytic framework. *Thinking Skills and Creativity, 33*, Article 100585.

Hennessey, B., & Amabile, T. (1987). *Creativity and learning: What research says to the teacher*. NEA Professional Library.

Henriksen, D., Mishra, P., & Fisser, P. (2016). Infusing creativity and technology in 21st century education: A systemic view for change. *Journal of Educational Technology & Society, 19*(3).

Henriksen, D., Richardson, C., & Mehta, R. (2017). Design thinking: A creative approach to educational problems of practice. *Thinking Skills and Creativity, 26*, 140–153.

Hernández Leo, D., Agostinho, S., Beardsley, M., Bennet, S., & Lockyer, L. (2017). Helping teachers to think about their design problem: A pilot study to stimulate design thinking. *Paper presented at 9th international conference on education and new learning technologies*. July 3, Retrieved from http://hdl.handle.net/10230/32247.

Hernández-Torrano, D., & Ibrayeva, L. (2020). Creativity and education: A bibliometric mapping of the research literature (1975-2019). *Thinking Skills and Creativity, 35*, Article 100625.

Hoogveld, A. W., Paas, F., & Jochems, W. M. (2005). Training higher education teachers for instructional design of competency-based education: Product-oriented versus process-oriented worked examples. *Teaching and Teacher Education, 21*(3), 287–297.

Howard, T. J., Culley, S. J., & Dekoninck, E. (2008). Describing the creative design process by the integration of engineering design and cognitive psychology literature. *Design Studies, 29*(2), 160–180.

Huidobro, T., & González, J. (2004). *Una definición de la creatividad a través del estudio de 24 autores seleccionado. (Doctoral dissertation)*. Retrieved from. Madrid, Spain: Universidad Complutense de Madrid https://eprints.ucm.es/4571/.

Ideo. (2013). *Design thinking for educators* Accessed 2 November 2018 https://designthinkingforeducators.com/.

Jordan, M. E. (2016). Teaching as designing: Preparing pre-service teachers for adaptive teaching. *Theory into Practice, 55*(3), 197–206.

Khalid, M., Saad, S., Hamid, S. R. A., Abdullah, M. R., Ibrahim, H., & Shahrill, M. (2020). Enhancing creativity and problem solving skills through creative problem solving in teaching mathematics. *Creativity Studies, 13*(2), 270–291.

Kirton, M. J. (2004). Problems with creativity. *Adaption-innovation: In the context of diversity and change* (pp. 135–141). Routledge.

Kleiman, P. (2008). Towards transformation: Conceptions of creativity in higher education. *Innovations in Education and Teaching International, 45*(3), 209–217.

Koehler, M. J., & Mishra, P. (2005). Teachers learning technology by design. *Journal of Computing in Teacher Education, 21*(3), 94–102.

Koski, M., & de Vries, M. (2015). An aid for teachers to teach science and technology concepts: Two studies to test the three-domain model. *International Journal of Technology and Design Education, 25*(2), 169–195.

Lee, M., & Erdogan, I. (2007). The effect of science–technology–society teaching on students' attitudes toward science and certain aspects of creativity. *International Journal of Science Education, 29*(11), 1315–1327.

Lego. (2018). *Kit lego for education* Accessed 4 December 2018 https://education.lego.com/en-us.

Lewis, T. (2009). Creativity in technology education: Providing children with glimpses of their inventive potential. *International Journal of Technology and Design Education, 19*(3), 255–268.

Lin, L., Shadiev, R., Hwang, W., & Shen, S. (2020). From knowledge and skills to digital works: An application of design thinking in the information technology course. *Thinking Skills and Creativity*, Article 100646.

Lodico, M. G., Spaulding, D. T., & Voegtle, K. H. (2010). *Methods in educational research: From theory to practice* (Vol. 28). John Wiley & Sons.

Logan, L. M., Logan, V. G., & García, A. R. (1980). *Estrategias para una enseñanza creativa*. Oikos-tau.

Lombardi, M. M. (2007). Authentic learning for the 21st century: An overview. *Educause Learning Initiative, 1*(2007), 1–12.

López, O. (2008). Enseñar creatividad: El espacio educativo. In *Cuadernos De La Facultad De Humanidades Y Ciencias Sociales.Universidad Nacional De Jujuy, 35* pp. 61–75).

Lor, R. (2017). Design thinking in education: A critical review of literature. May *Paper presented at Asian conference on education & psychology*.

MacLaren, I. (2012). The contradictions of policy and practice: Creativity in higher education. *London Review of Education, 10*(2), 159–172.

McMullan, M. J. (2016). How using technology enhanced learning could help modernise traditional large group teaching or lecturing. *International Journal of Innovative Research in Medical Science (IJIRMS) (Online)*, 2245–8737.

Merriam, S. B. (1988). *Case study research in education: A qualitative approach*. Jossey-Bass.

Mishra, P., & Mehta, R. (2017). What we educators get wrong about 21st-century learning: Results of a survey. *Journal of Digital Learning in Teacher Education, 33*(1), 6–19.

Mosely, G., Wright, N., & Wrigley, C. (2018). Facilitating design thinking: A comparison of design expertise. *Thinking Skills and Creativity, 27*, 177–189.

Nakano, T.d. C., & Wechsler, S. M. (2018). Creativity and innovation: Skills for the 21st century. *Estudos De Psicologia (Campinas), 35*(3), 237–246.

Nguyen, K., DeMonbrun, R. M., Borrego, M., Prince, M., Husman, J., Finelli, C. J., et al. (2017). The variation of nontraditional teaching methods across 17 undergraduate engineering classrooms. June 24 *Paper presented at the 2017 ASEE annual conference & exposition*.

Norton, P., & Hathaway, D. (2015). In search of a teacher education curriculum: Appropriating a design lens to solve problems of practice. *Educational Technology*, 3–14.

Page, T., & Thorsteinsson, G. (2017). Teaching creativity across the curriculum through design education? *I-Manager's Journal of Educational Technology, 14*(1), 7.

Parkhurst, H. B. (1999). Confusion, lack of consensus, and the definition of creativity as a construct. *The Journal of Creative Behavior, 33*(1), 1–21.

Patton, M. Q. (2014). *Qualitative research & evaluation methods: Integrating theory and practice*. Sage publications.

Peterson, R. E. (2001). Establishing the creative environment in technology education: Creativity doesn't just happen by chance; the prepared environment nourished it. *The Technology Teacher, 61*(4), 7–11.

Ponterotto, J. G. (2005). Qualitative research training in counseling psychology: A survey of directors of training. *Teaching of Psychology, 32*(1), 60–62.

Qi, J. (2017). An optimization approach for flipped classroom and multimedia teaching innovation by contrast with traditional teaching. *Boletín Técnico*. ISSN: 0376-0723X, 55(8).

Rauth, I., Köppen, E., Jobst, B., & Meinel, C. (2010). Design thinking: An educational model towards creative confidence. November 29 *Paper Presented at the 1st international conference on design creativity (ICDC 2010)*.

Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important? *Review of Educational Research, 82*(3), 330–348.

Reiter-Palmon, R., & Illies, J. J. (2004). Leadership and creativity: Understanding leadership from a creative problem-solving perspective. *The Leadership Quarterly, 15*(1), 55–77.

Retna, K. S. (2016). Thinking about "design thinking": A study of teacher experiences. *Asia Pacific Journal of Education, 36*(Suppl. 1), 5–19.

Seltzer, K., & Bentley, T. (1999). *The creative age: Knowledge and skills for the new economy*. Demos.

Şendurur, E., Ersoy, E., & Çetin, İ. (2016). The design and development of creative instructional materials: The role of domain familiarity for creative solutions. *International Journal of Technology and Design Education*, 1–16.

Shaheen, R. (2010). Creativity and education. *Creative Education, 1*(03), 166.

Simonton, D. K. (2000). Creativity: Cognitive, personal, developmental, and social aspects. *American Psychologist, 55*(1), 151.

Spencer, D., & Warfel, T. (2004). Card sorting: A definitive guide. *Boxes and Arrows, 2*, 1–23.

Spendlove, D. (2008). Creativity in education: A review. *Design and Technology Education: An International Journal, 10*(2).

Sternberg, R. J., & Lubart, T. I. (1997). *La creatividad en una cultura conformista: Un desafío a las masas*. Paidós.

Thapa, A., Cohen, J., Guffey, S., & Higgins-D'Alessandro, A. (2013). A review of school climate research. *Review of Educational Research, 83*(3), 357–385.

Thorsteinsson, G., & Page, T. (2017). Teaching creativity across the curriculum through design education. Case studies. *Educatia, 21*(15), 13–22.

Topping, K. J. (2005). Trends in peer learning. *Educational Psychology, 25*(6), 631–645.

Torrance, E. (1972). Can we teach children to think creatively? *The Journal of Creative Behavior, 6*(2), 114–143.

Torre, d.l. S., & Violant, V. (2006). *Comprender y evaluar la creatividad.Cómo investigar y evaluar la creatividad*. Albije.

Tulsi, P., & Poonia, M. (2015). Expectations of industry from technical graduates: Implications for curriculum and instructional processes. *Journal of Engineering Education Transformations*, 19–24.

Tuning, P. (2003). *Tuning educational structures in Europe. Informe final*. Bilbao: Universidad de Deusto.

Twenty one toys. (2018). *The empathy toy teacher's kit* Accessed 19 December 2018 https://twentyonetoys.com/collections/toys-games-play-based-learning/products/empathy-toy-teachers-kit.

Valero, A. (2018). Así es el aula que prepara para las habilidades del futuro, según bMaker. *Business Inside*. November 14, Retrieved from https://www.businessinsider.es.

Vass, E. (2017). Building dialogic spaces through inclusive conversations. *Engaging schooling: Developing exemplary education for students in poverty* (p. 63).
Voelkl, K. E. (1995). School warmth, student participation, and achievement. *The Journal of Experimental Education, 63*(2), 127–138.
Wilson, A. (2005). *Creativity in primary education: Theory and practice (achieving QTS cross-curricular strand)*. Learning Matters.
Withers, C., Methven, L., Qannari, E., Allen, V., Gosney, M., & MacFie, H. (2014). Taxonomic free sorting: A successful method with older consumers and a novel approach to preference mapping. *Journal of Sensory Studies, 29*(3), 182–189.
Zhang, W., & Guo, A. (2017). Research on the blended teaching mode for computer network course. July 1 *Paper presented at the 4th international conference on social science and humanity*.
Zhao, J., & Meng, Z. (2015). Information transfer technique in classroom interaction. *US-China Foreign Language*, 357.

3.2. Estudio 2

Calavia, M.B., Blanco, T., & Casas. R. (2019). Recursos basados en el diseño para fomentar la creatividad en el aula. In *V International Conference on Learning, Innovation and Competitiveness (CINAIC)* (pp. 590-595). Madrid, España. http://dx.doi.org/10.26754/CINAIC.2019.0120

BD: N/A

Recursos basados en el diseño para fomentar la creatividad en el aula

Design-based resources to foster creativity in the classroom

Mª Belén Calavia Ferrández[1,2], Teresa Blanco Bascuas[1,2], Roberto Casas Nebra[1,3]
bcalavia@unizar.es, tblanco@unizar.es, rcasas@unizar.es

[1]HOWLab (Human OpenWare Research Group)
Instituto de Investigación en Ingeniería de Aragón
Zaragoza, España

[2]Departamento de Ingeniería de Diseño y Fabricación
Universidad de Zaragoza
Zaragoza, España

[3]Departamento de Ingeniería Electrónica y Comunicaciones
Universidad de Zaragoza
Zaragoza, España

Resumen- En los últimos años se ha incrementado el interés en formar a los alumnos en competencias transversales como la creatividad. Sin embargo, dicho enfoque no siempre se traduce a nivel práctico; porqué las escuelas no producen personas más creativas es una pregunta que actualmente no tiene respuesta. Un posible foco de actuación es el desarrollo de nuevos recursos que conecten a docentes y alumnos dentro del entorno educativo. En este artículo se presenta una experiencia de aprendizaje en el ámbito de secundaria a partir de una nueva metodología basada en el pensamiento de diseño, y destinada a contribuir en la formación de individuos más creativos. Se concluye que la metodología desarrollada se integra positivamente en el currículo, y es reconocida de gran ayuda para fomentar la creatividad en las escuelas. Asimismo, se evidencia la oportunidad que tiene el campo de la ingeniería de diseño en este y en otros posibles entornos educativos.

Palabras clave: Creatividad; Pensamiento de diseño; Nuevos Recursos; Métodos educativos

Abstract- In the last years, there has been a growing interest in training students in transversal competences as the creativity. However, such approach has not been always translated into the practical level; why schools fail to produce more creative students is a question that does not currently have an answer. One possible action is the development of new resources to connect teachers and students in the educational environments. This paper presents a high school learning experience by using a new methodology based on design thinking and aimed to produce more creative people. It is concluded that the developed methodology is positively integrated into the teaching curriculum, and it is recognized as a great help to foster creativity in the schools. Additionally, the opportunity of design engineering field in this and others educational environment is evidenced.

Keywords: Creativity; Design Thinking; New Resources; Educational Methods

1. Introducción

Hoy en día, en los distintos sectores de trabajo, se precisa cada vez más de individuos con capacidades transversales, lo que requiere formar a los futuros profesionales de manera diferente (Bullen & Morgan, 2016; Daly, Adams, & Bodner, 2012; Gallardo-Echenique, Marqués-Molías, Bullen, & Strijbos, 2015; Jenkins, Purushotma, Weigel, Clinton, & Robison, 2009; Tulsi & Poonia, 2015). Por ello, en los últimos años se han producido importantes cambios en la enseñanza, en los que el enfoque educativo basado en competencias ha venido a modificar la metodología tradicional (Blanco, López-Forniés, & Zarazaga-Soria, 2017). De esta forma, el estudiante no sólo adquiere conocimientos, sino que tiene que desarrollar habilidades; mientras el profesor actúa como proveedor de recursos.

En esta línea, una de las competencias más fundamentales es la creatividad; entendida como capacidad de resolver problemas de un modo innovador (Wong & Siu, 2012); y considerada una "habilidad de pensamiento del siglo XXI" (Henriksen, Richardson, & Mehta, 2017). La capacidad creativa no es un talento limitado a algunas personas, sino que está presente en todos los seres humanos, en mayor o menor medida (Guilford, 1950). Por tanto, la creatividad es un potencial innato que se despierta, estimula y desarrolla a través de la educación, del trabajo y de un entrenamiento adecuado en un ambiente propicio (López, 2008).

Por todo ello resulta innegable que los entornos educativos son clave para desarrollar la capacidad creativa (Shaheen, 2010). Sin embargo, se puede aseverar que en la práctica, los ámbitos educativos no se centran en "generar" individuos creativos (Henriksen et al., 2017). Asimismo, es patente la necesidad de desarrollar soluciones prácticas (métodos, recursos y herramientas) que ayuden a los docentes a introducir y fomentar la creatividad en sus aulas. Cabe destacar que para el desarrollo de este tipo de recursos se deben abordar algunos desafíos tales como: el uso frecuente de la metodología tradicional basada en la instrucción del maestro; las dificultades y limitaciones del sistema educativo; y la interpretación del término "creatividad".

Ante esta situación, las metodologías adscritas al pensamiento de diseño (Maguire, 2001), colaborativas e integradas en los procesos de innovación, resultan de especial interés, ya que pueden ser utilizadas por docentes y alumnos para descubrir nuevas formas de trabajo y de desarrollo competencial. De hecho, la creatividad se asocia y se potencia en la educación gracias al diseño (Thorsteinsson & Page, 2017); este campo proporciona a los estudiantes una mente más abierta, y crea un contexto que fomenta la creatividad como un elemento transversal, utilizando el conocimiento de todas las materias para resolver problemas (Page & Thorsteinsson, 2017).

En este contexto, se presenta una experiencia de aprendizaje a partir de la aplicación de una nueva metodología

DOI: 10.26754/CINAIC.2019.0120

denominada "Learning by Challenges" (LBC); planteada desde las bases de la ingeniería de diseño y enfocada a la formación de individuos más creativos. La principal aportación de la experiencia es utilizar en el ámbito escolar una nueva herramienta para trabajar el desarrollo competencial de los alumnos.

2. CONTEXTO

Tal y como se ha visto en la introducción, el porqué las escuelas no producen personas más creativas (Guilford, 1950) es una pregunta que, en ocasiones, continúa sin tener respuesta. En consecuencia, este estudio pretende ayudar a fomentar la creatividad a partir de la metodología desarrollada y su aplicación en un contexto real. Los principales objetivos establecidos en este proyecto de investigación educativa son los siguientes:

· Buscar formas de aprendizaje competencial, diferentes a la copia, la memoria o la reproducción.

· Evidenciar la importancia de la creatividad como una competencia básica a desarrollar dentro del currículo escolar.

· Comprobar si al utilizar la metodología desarrollada (LBC) se mantiene el currículo en tiempo y alcance.

· Verificar que LBC cumple su cometido, haciendo que los alumnos trabajen en la resolución de problemas y puedan aplicar este aprendizaje en cualquier ámbito o disciplina.

· Demostrar la notable aportación del campo de la ingeniería de diseño en este ámbito.

El marco de trabajo para la experiencia que se expone en el presente documento se establece en un instituto de educación secundaria, en concreto en dos clases de 4º de la ESO, con una muestra total de 46 alumnos y 2 profesores. De los grupos estudiados, el grupo B (23 alumnos), según la experiencia previa de sus docentes, cuenta con un núcleo de alumnos con una motivación por el estudio media-alta, que hipotéticamente influirá de manera positiva en el uso de la herramienta. El grupo C (23 alumnos), bajo el mismo criterio, cuenta con un núcleo de alumnos con una motivación por el estudio media baja, lo que hipotéticamente puede influir en una actitud más pasiva durante las clases. El perfil de usuario principal corresponde al maestro, usuario de la metodología de primer nivel, ya que la interpreta y aplica. El perfil de usuario secundario corresponde al estudiante, como usuario final que se beneficia de la implementación.

La herramienta se adapta a los contenidos de la unidad didáctica "La dinámica de la Tierra" de la asignatura de Biología y Geología. Asimismo, la experimentación se lleva cabo en las mismas sesiones teóricas dedicadas a la unidad didáctica, es decir, durante 6 sesiones de 50 minutos repartidas en dos semanas, en cada una de las clases.

3. DESCRIPCIÓN

LBC tiene como objetivo ayudar al docente a aplicar el pensamiento de diseño en el aula. Para ello, el profesor plantea los problemas como desafíos para impulsar la capacidad creativa de los estudiantes, y establecer nuevas posibilidades de aprendizaje competencial. Los fundamentos teóricos que soportan la metodología aúnan bases del diseño industrial y del Project Based Learning (Blumenfeld et al., 1991), con un trabajo de investigación específico en torno a los factores que influyen en el desarrollo de la creatividad como resolución de problemas. La metodología se compone de cuatro fases de trabajo identificadas con diferentes colores (Figura 1).

Figura 1. Fases de la metodología Learning By Challenges

En la figura 2 se muestra el prototipo físico del kit desarrollado para implementar la metodología LBC. El kit está compuesto por tres tipos de materiales; manual para enseñar por retos; plantillas complementarias; y materiales complementarios. El manual, considerado el núcleo del kit, está formado por tarjetas que explican al docente cómo usar la metodología. Asimismo, las plantillas son hojas guía para complementar las actividades del manual. Por último, los materiales complementarios, como post-its, pegatinas, cronómetro, marcadores, etc., son elementos necesarios para llevar a cabo las actividades.

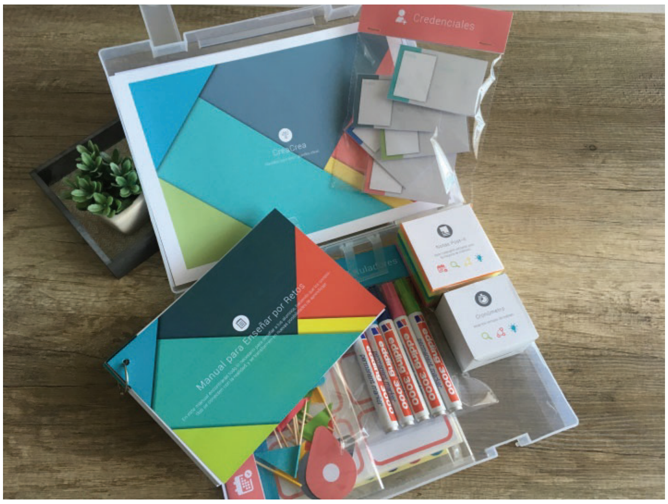


Figura 2. Kit de Learning By Challenges

Una descripción pormenorizada de la herramienta y teoría asociada se puede encontrar en Calavia et al. (2019b).

A continuación se detalla la aplicación de la metodología según sus fases:

- FASE 0: INTEGRACIÓN

Es una fase previa destinada a presentar el recurso y despertar el interés del profesorado. Se contacta con los docentes para mostrarles el proyecto y su cometido; posteriormente se explica y aconseja a los educadores sobre cómo integrar la metodología en el aula.

- FASE 1: PREPARACIÓN

Tal y como define LBC, previamente a la aplicación en el aula, se requiere preparación para planificar y determinar las actividades. Para ello, el profesorado utiliza el kit (Figura 3); lee las tarjetas, completa las fichas, y emplea los materiales incluidos. Durante estas sesiones se consideran las restricciones de temario asignado, tiempo, espacio, número de alumnos, capacidades de los alumnos, y competencias más relevantes. El profesorado determina:

· Temario: "La Dinámica de la Tierra" de la asignatura de "Biología y Geología".

· Reto/Desafío: ¿Cómo podríamos proteger las ciudades sensibles a las catástrofes naturales? Que conecta los contenidos del temario con la realidad de alumno y beneficia el aprendizaje social.

· Tiempo y planificación: Seis sesiones de cincuenta minutos.

· Grupo: La clase se divide en grupos de cinco estudiantes, según los equipos establecidos en trabajos anteriores.

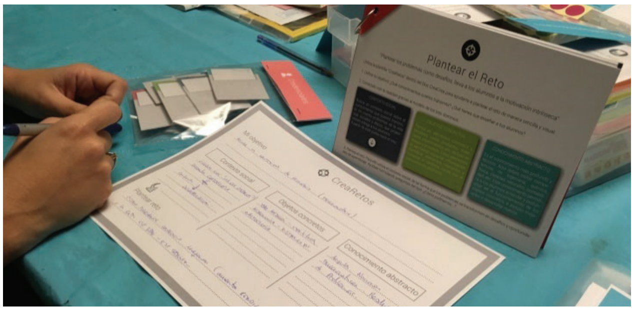


Figura 3. Preparación previa realizada por el docente

- FASE 2: APLICACIÓN

A continuación se describe la aplicación en el aula.

2.1 Presentación e Investigación (Primera sesión): Sobre la pizarra se colocan noticias relevantes relacionadas con el temario, por ejemplo la aparición de una grieta kilométrica en África, Fukushima o el salto de Baumgartner. Se anima a los alumnos a ponerse de pie y se lleva a cabo una dinámica colaborativa, colocando post-its sobre lo que conocen o les inspira cada noticia (Figura 4). Después de la puesta en común, el docente profundiza en la explicación y vincula las noticias con la teoría. A continuación, la clase se divide en grupos de 4 o 5 estudiantes, y se les asignan roles que escriben en sus credenciales. A cada grupo se le entrega una noticia y la rúbrica con las especificaciones y la evaluación del proyecto. Cada grupo debe investigar una noticia. Se invita al estudiante a utilizar el material complementario: pegatinas de dudas, ejemplos de preguntas, hojas grandes, etc.

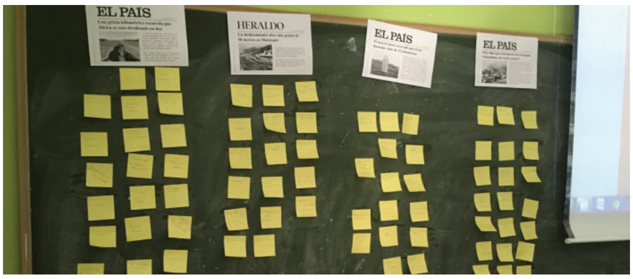


Figura 4. Lluvia de información

2.2 Síntesis de la información (Segunda sesión): Cada alumno pone en común la información con su grupo. Posteriormente sintetizan la información y, para ello, crean mapas mentales a partir del material complementario (Figura 5). El profesor establece el tiempo con el cronómetro mientras los alumnos sintetizan e interpretan la información. El docente dedica unos 7' a cada grupo y les aporta retroalimentación y motivación (coloca pegatinas con comentarios, "me gustas", cuestiones, etc.).

Figura 5. Síntesis de la investigación

2.3 Comunicación de los resultados (Tercera y cuarta sesión): Cada grupo presenta su tema al resto de compañeros. Después de cada presentación, el profesor completa la explicación y corrige la información errónea.

2.4 Ideación (Quinta sesión): Esta clase se dedica a la obtención de soluciones para el reto planteado. Para la ideación, los alumnos utilizan los materiales y las técnicas de diseño incluidas en el kit (Figura 6) como la metodología 635 de Rohrbach (1969); a su vez el docente mide los tiempos y aporta retroalimentación.

Figura 6. Materiales incluidos en el kit de la metodología

2.5 Conceptualización y autoevaluación (Sexta sesión): Cada grupo define un concepto a partir de la ideación, para ello utiliza el material de selección y desarrollo (Figura 7). Posteriormente cada grupo presenta su concepto al resto de compañeros, y se discuten sus ventajas e inconvenientes. Por último, cada alumno realiza la ficha de autoevaluación incluida en el kit, en la que deben marcar aspectos positivos y aspectos a mejorar sobre su trabajo, el trabajo de su equipo y el trabajo de otro equipo.

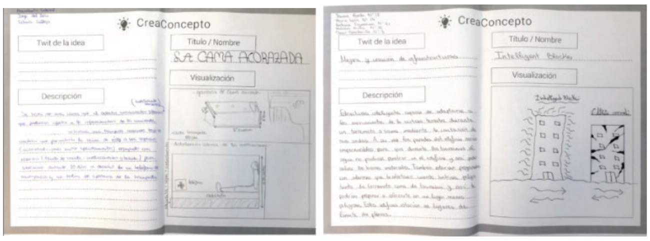


Figura 7. Conceptualización

Aunque no está considerado por la metodología, el profesor decide hacer un examen de preguntas cortas para evaluar los conocimientos.

4. Resultados

La evaluación de los resultados obtenidos se lleva a cabo mediante una estrategia metodológica basada en Xassess (Blanco, Berbegal, Blasco, & Casas, 2016), adaptada en este caso, a la idiosincrasia del escenario de educación, y enfocada a la evaluación colaborativa entre diferentes especialidades. Una descripción pormenorizada de cómo evaluar una herramienta de este tipo se puede encontrar en Calavia, Blanco & Casas (2019a).

A nivel general, el objetivo de la evaluación es validar el cometido de la metodología en el contexto real (con estudiantes y profesores), y obtener retroalimentación necesaria para el diseño final de un producto finalista y susceptible de someterse a una evaluación más en masa. Se establecen las siguientes dimensiones a evaluar:

· Incorporación y adaptación al entorno y el currículo.

· Adecuación del material.

· Ambiente didáctico y cómodo.

· Motivación de los alumnos.

· Compresión y entendimiento de conceptos.

· Trabajo en equipo.

· Divergencia.

· Tiempo de reflexión y autoevaluación.

· Opinión general de la herramienta.

Para abordarlas, durante la experimentación, se sigue una estrategia de evaluación combinatoria de métodos de evaluación cualitativos y cuantitativos (Cada dimensión de la herramienta se evalúa con varios métodos de evaluación que se complementan entre sí). De esta forma, se garantiza la validez de los resultados. Entre los métodos cuantitativos utilizados se encuentran los tests, las escalas sistematizadas de observación, y la encuesta de satisfacción; mientras que de métodos cualitativos se emplean las técnicas de observación de usuario, las entrevistas semiestructuradas en profundidad, y los grupos de discusión.

La elección de métodos y estrategias ha dependido directamente de cada una de las dimensiones, siempre clasificadas bajo dos perspectivas: la del docente y la del alumno. Para mayor detalle acerca de los objetivos e indicadores de evaluación, las estrategias, los instrumentos y los factores, véase Calavia, Blanco & Casas (2019b).

A partir de los resultados se puede afirmar que la calidad del material ha sido considerada por los docentes como un elemento clave para el éxito de la herramienta. Aseguran que está cuidado y preparado, y valoran positivamente el peso que tiene la disciplina de diseño para el desarrollo de los materiales "yo creo que este material hace que a los alumnos les entre curiosidad, participen más y les guste más. Esta misma metodología se puede hacer de una forma austera, bizarra, en un folio… y no se hubiesen obtenido los mismos resultados. Las cosas no son solo lo que cuentas, sino cómo lo cuentas". Asimismo, el 85,2% de los alumnos considera que han notado la diferencia con los materiales utilizados en otras clases "son materiales más didácticos y prácticos con los que no estamos acostumbrados a trabajar en 4º E.S.O".

El profesorado considera que el clima durante las sesiones ha sido bueno "el clima fue agradable gracias a las actividades. Súper cómodo y muy tranquilo". Igualmente, aseveran que este ambiente ha favorecido a adoptar una buena actitud por parte de los alumnos "se ha propiciado mucho más la participación y con mayor intensidad que normalmente". En relación a ello, la mayoría de los alumnos (81,5%) afirma que ha participado más en estas clases que en otras ocasiones. Los alumnos comentan "es un método totalmente novedoso para nosotros, no era una clase normal, por lo que estábamos más abiertos a participar y la esperábamos con ganas". A la hora de describir cómo se han sentido durante las clases, "cómodo" ha sido el más utilizado, seguido de "satisfecho" y "motivado".

En cuanto a las actividades realizadas, el profesor en formación comenta que "las actividades las han recibido con interés y motivación, ya que es un tipo de ejercicio que se sale de las clases magistrales habituales". En esta línea, el 81,5% de los alumnos afirma que se ha sentido más motivado durante las clases. Entre las actividades realizadas, los alumnos valoran positivamente las relacionadas con el pensamiento divergente "me gusta aportar mis conocimientos y una solución (medianamente posible) a un problema actual". Las soluciones planteadas por los estudiantes son muy diversas (Figura 7); algunas se centran en la construcción de edificios "inteligentes" o una cama "acorazada", otras buscan acabar con las corrientes de convección para que las placas paralicen su movimiento, incluso investigar sobre la estructura interna viajando al centro de la Tierra, o educar en los colegios acerca de qué hacer ante una situación de emergencia.

Ambos docentes explican que los resultados demuestran que los alumnos han comprendido los conceptos (Tabla 2). Cada una de las sesiones es evaluada y al finalizar se realiza un examen. Los resultados son buenos, si bien en el grupo A son superiores, tal y como se esperaba debido a la diferencia de nivel; no obstante, el profesorado señala "ha sido mejor de lo que esperábamos, en este grupo la motivación es muy baja". No obstante, comentan en general que "se nota que van muy guiados en el día a día y cuando se realiza algo distinto les cuesta ser proactivos y creativos".

Tabla 1. Calificaciones de los estudiantes

	Trabajo en grupo	Examen	Nota final
Media resultados 4º A	9.3 ± 0.5	7.9 ± 1.3	8.7 ±0.8
Media resultados 4º B	8.1 ±0.8	5.4 ± 2	7 ± 1.1

Hay reflexiones de los estudiantes sobre el aprendizaje y la comprensión de conceptos:

- Se ha logrado un aprendizaje diferente “he aprendido muchas cosas sin estudiar mucho rato con los libros, sin quererlo, simplemente con investigar o escuchar”.

- Se ha conectado el temario con la vida de los alumnos a través de los retos planteados “me ha gustado trabajar de forma más dinámica un tema que no me llamaba nada la atención, y ahora lo veo más interesante”.

- Se ha mejorado la autonomía de los alumnos “me ha gustado buscar yo mismo la información, descubría cosas que no sabía, como datos curiosidades…”.

A la hora de autoevaluar su trabajo, la mayoría de alumnos reflexionan sobre dos cuestiones principales: la necesidad de mejorar sus presentaciones orales “me gustaría explicar mejor, más fácilmente y sin vergüenza. No soy bueno presentando”; y la falta de tiempo para las actividades de carácter tradicional "me gustaría tener más clases para mejorar la presentación y resumir el contenido del examen", ya que consideran que son las actividades evaluadas.

En general sobre la metodología los maestros consideran que es interesante y les gustaría usarla en sus clases para que los estudiantes se involucren más "mi opinión es tremendamente positiva (...) la tarea (...) se logra de manera muy amplia. Además, a pesar de ser aplicado en un tema con poco “jugo”, se han logrado muy buenos resultados". Igualmente, el 96% de los estudiantes afirma que les gustaría usar esta metodología en otras clases "me gustaría que tuviéramos la oportunidad de trabajar con esta metodología al menos una vez por trimestre". Por el contrario, un estudiante comentó: "tenía miedo del examen porque la clase fue muy práctica”. Esto coincide con los comentarios de los maestros sobre el hábito de clases estructuradas y guionizadas.

Por tanto, a partir de los hallazgos obtenidos durante la investigación, se puede afirmar que se cumple con los objetivos establecidos para el presente proyecto de investigación educativa.

5. Conclusiones

Como conclusión se puede aseverar que la metodología desarrollada comparte las mismas líneas y sigue los principios del currículo actual basado en competencias, sin entrar en confrontación con ninguno de ellos, por lo que se integra adecuadamente en el programa actual de enseñanza, manteniendo el currículo en tiempo y alcance. Asimismo, se ha evidenciado que la metodología propuesta contempla todos los factores clave para mejorar la creatividad (como el trabajo en equipo, la divergencia, el aumento de participación, la motivación intrínseca o la autoevaluación). Por tanto, se puede afirmar que LBC ayuda al profesor a producir personas más creativas, y crea nuevas posibilidades de aprendizaje competencial; siendo formación clave para el futuro empleo y papel en la sociedad de los estudiantes.

No obstante, el equipo ha detectado algunos aspectos a mejorar como la necesidad de formar al docente previamente, lo que coincide con una de las hipótesis iniciales de utilizar la metodología para la formación a docentes. Existen también múltiples posibilidades de mejora en LBC; considerar la inclusión de tecnología para que sea más novedosa y acorde a la realidad de los alumnos; o trabajar la presentación oral, entre otras.

Como vía de desarrollo futuro, cabe destacar la posibilidad que tiene el campo de la ingeniería de diseño dentro de la educación. Se demuestra que esta disciplina supone una base de conocimiento y de recursos que pueden ser extrapolados y adaptados al ámbito educativo, así como un importante punto de partida en el desarrollo de herramientas innovadoras que favorezcan el fomento de la creatividad.

Agradecimientos

Agradecer a todos los estudiantes, docentes y entidades involucradas en el estudio.

Financiado por el Gobierno de Aragón (T27_17R) (BOA20180615027) y cofinanciado con Feder 2014-2020 “Construyendo Europa desde Aragón”.

Referencias

Blanco, T., Berbegal, A., Blasco, R., & Casas, R. (2016). Xassess: Crossdisciplinary framework in user-centred design of assistive products. *Journal of Engineering Design, 27*(9), 636-664.

Blanco, T., López-Forniés, I., & Zarazaga-Soria, F. J. (2017). Deconstructing the tower of babel: A design method to improve empathy and teamwork competences of informatics students. *International Journal of Technology and Design Education, 27*(2), 307-328.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3-4), 369-398.

Bullen, M., & Morgan, T. (2016). Digital learners not digital natives. *La Cuestión Universitaria,* (7), 60-68.

Calavia, M.B., Blanco, T., Casas, R. (2019a). *Formando a personas creativas en la era digital. Evaluación x-disciplinar de una herramienta basada en el diseño* Revisiones sobre Arte, patrimonio y tecnología en la era digital, Zaragoza, IAACC Pablo Serrano, Gobierno de Aragón, 216-226.

Calavia, M.B., Blanco, T., & Casas, R. (2019b). Fostering creativity as a problem-solving competence: Learning by Challenges, a resource for teachers based on design engineering (preprint).

Daly, S. R., Adams, R. S., & Bodner, G. M. (2012). What does it mean to design? A qualitative investigation of design professionals' experiences. *Journal of Engineering Education, 101*(2), 187-219.

Gallardo-Echenique, E. E., Marqués-Molías, L., Bullen, M., & Strijbos, J. (2015). Let’s talk about digital learners in the digital era. *The International Review of Research in Open and Distributed Learning, 16*(3)

Guilford, J. P. (1950). Creativity. *American Psychologist, 5*(9), 444-454.

Henriksen, D., Richardson, C., & Mehta, R. (2017). Design thinking: A creative approach to educational problems of practice. *Thinking Skills and Creativity, 26*, 140-153.

Jenkins, H., Purushotma, R., Weigel, M., Clinton, K., & Robison, A. J. (2009). *Confronting the challenges of participatory culture: Media education for the 21st century* Mit Press.

López, O. (2008). Enseñar creatividad: El espacio educativo. *Cuadernos De La Facultad De Humanidades Y Ciencias Sociales.Universidad Nacional De Jujuy,* (35), 61-75.

Maguire, M. (2001). Methods to support human-centred design. *International Journal of Human-Computer Studies, 55*(4), 587-634.

Page, T., & Thorsteinsson, G. (2017). Teaching creativity across the curriculum through design education? *I-Manager's Journal of Educational Technology, 14*(1), 7.

Rohrbach, B. (1969). Creative by rules—method 635, a new technique for solving problems. *Absatzwirtschaft, 12*, 73-75.

Shaheen, R. (2010). Creativity and education. *Online Submission, 1*(3), 166-169.

Thorsteinsson, G., & Page, T. (2017). Teaching creativity across the curriculum through design education. case studies. *Educatia 21,* (15), 13-22.

Tulsi, P., & Poonia, M. (2015). Expectations of industry from technical graduates: Implications for curriculum and instructional processes. *Journal of Engineering Education Transformations,* , 19-24.

Wong, Y. L., & Siu, K. W. M. (2012). A model of creative design process for fostering creativity of students in design education. *International Journal of Technology and Design Education, 22*(4), 437-45.

3.3. Estudio 3

Calavia, M.B., Blanco, T., & Casas. R. (2019). Formando a personas creativas en la era digital. Evaluación x- disciplinar de una herramienta basada en el diseño. In Foradada, C. & Irala-Hortal, P. (Eds.), *Re_Visiones sobre arte, patrimonio y tecnología en la era digital* (pp. 185-194). Gobierno de Aragón.

ISBN: 978-84-8380-411-7

BD: N/A

2.5. Formando a personas creativas en la era digital. Evaluación x-disciplinar de una herramienta basada en el diseño

Mª Belén Calavia Ferrández[1]
Teresa Blanco Bascuas[1]
Roberto Casas Nebra[1]

1. Introducción

En un mundo en el que los avances tecnológicos cobran cada vez mayor alcance, la era digital ha ocasionado cambios en la innovación a distintos niveles, generado importantes repercusiones en todas las áreas de la sociedad (Gisbert & Esteve, 2016). El motor de la innovación tecnológica ahora ya no se ciñe exclusivamente al progreso intrínseco de la propia tecnología, sino que también entran en juego aquellos cambios que se introducen deliberadamente en el significado del producto (Norman & Verganti, 2014) y los nuevos modelos de comportamiento de la sociedad; es decir, la innovación también puede ser inducida por la prospección en nuevos modos de entender, usar, e interactuar y por la consideración de nuevas formas de interrelación entre humanos y tecnología (Blanco, 2016). En consecuencia, es cada vez mayor la demanda de equipos con capacidades transversales, lo que requiere formar a los futuros profesionales de manera diferente (Bullen & Morgan, 2016; Daly, Adams, & Bodner, 2012; Gallardo- Echenique, Marqués-Molías, Bullen, & Strijbos, 2015; Jenkins, Purushotma, Weigel, Clinton, & Robison,2009; Tulsi & Poonia, 2015).

En línea con esto, en los últimos años, el enfoque educativo basado en competencias ha venido a modificar la metodología tradicional (Blanco, López-Forniés, & Zarazaga-Soria, 2017) principalmente fundamentada en la instrucción del maestro, y el aprendizaje a través de la copia, la memoria o la reproducción (Lee & Erdogan, 2007). La competencia se entiende como la combinación dinámica de conocimiento, entendimiento, capacidades y habilidades que preparan a los estudiantes para su futuro empleo y papel en la sociedad (Tuning, 2003); sin embargo estas suelen ser difíciles de transmitir a los estudiantes (Wilhelm, Logan, Smith, & Szul, 2002). Una de las competencias más fundamentales en la era digital es la creatividad, entendida no como concepto ligado a lo artístico sino en su acepción más amplia, como capacidad de resolver problemas de un modo innovador frente a un mundo cambiante (Wong & Siu, 2012). La creatividad es considerada una "habilidad de pensamiento del siglo XXI" (Henriksen, Richardson, & Mehta, 2017), por el papel que desempeña en la capacidad del individuo en aprovechar y conectar conocimientos aprendidos con el objetivo de resolver problemas complejos y crear cosas (Kleiman, 2008).

El desarrollo de este potencial requiere de educación y trabajo en un ambiente propicio desde las primeras etapas de la vida (Burkus, 2013; López Martínez, 2008). Por tanto, es indiscutible el hecho de que los colegios son entornos clave para potenciar la creatividad, que debe estar presente en 4 pilares (fig. 1) en los que se fundamenta el desarrollo creativo (López Martínez, 2008).

Sin embargo, a pesar de lo antedicho, los ámbitos educativos no se centran en "generar" individuos creativos (Henriksen et al., 2017). Esto se debe a ciertos condicionantes de naturaleza muy variada, tales como la tendencia tradicional de muchas escuelas; el perfil y la motivación de cada docente; la rigidez administrativa y estructural de los centros; y la compleja aplicación de este área de conocimiento

1] Afiliación: HOWLab (Human OpenWare Research Group) Instituto de Investigación en Ingeniería de Aragón (I3A) Universidad de Zaragoza, Mariano Esquillor s/n, 50018, Zaragoza, España. Tel. +34-876555464, e-mail: tblanco@unizar.es

Fig. 1. Creatividad en todo el sistema.

(Lee & Erdogan, 2007; López Martínez, 2008). Ante esta situación, un posible enfoque para el fomento de la creatividad en todo el sistema es el desarrollo de soluciones prácticas (recursos y herramientas), que ayuden a docentes y alumnos a desarrollar esta habilidad, ya que, tal y como se observa en la figura 1, los recursos conectan a docentes y alumnos dentro del entorno educativo.

Uno de los ámbitos de conocimiento cuya inclusión en las estrategias puede tener una influencia destacada es la disciplina del diseño y sus bases. El diseño puede proporcionar a los estudiantes una mente más abierta; crear un contexto de fomento de la creatividad como elemento transversal, utilizando el conocimiento de todas las materias para resolver problemas (Page & Thorsteinsson, 2017; Thorsteinsson & Page, 2017); así como ofrecer la visión para hallar soluciones creativas a problemas complejos (Henriksen et al., 2017). No obstante, tratándose de un entorno tan complejo como trascendente, la inclusión en el entorno educativo de herramientas basadas en el diseño requiere de un elevado grado de x-disciplinaridad (denominado así al término común entre todas las posibilidades de trabajo colaborativo: multi-, cros-, inter-, trans- (Blanco, 2016), escuchando todas las voces acreditadas, tanto en el proceso de desarrollo de las herramientas, como en el proceso o procesos de evaluación de las mismas.

En este documento se presenta, mediante un caso de estudio, la evaluación de una nueva herramienta denominada “Manual para enseñar por retos”, planteada desde las bases del diseño y enfocada a la formación de individuos más creativos en la resolución de problemas y en la búsqueda de la innovación en la presente era. A partir de este caso, discutimos sobre las claves que permiten obtener conclusiones de valor, así como sobre las ventajas y dificultades derivadas de aplicar una evaluación colaborativa.

2. Materiales y métodos

El trabajo parte del desarrollo del “Manual para enseñar por retos”, una herramienta en forma de kit para profesores, cuyo objetivo es ayudar al docente a aplicar el pensamiento de diseño en el aula, planteando los problemas como desafíos, fomentando la capacidad creativa del alumno y abriendo nuevas posibilidades de aprendizaje competencial. Los fundamentos teóricos que lo soportan aúnan bases del diseño industrial y del Project Based Learning (Blumenfeld et al., 1991), con un trabajo de investigación específico en torno a los factores que influyen en el desarrollo de la creatividad como resolución de problemas. El manual consta de tarjetas de guía y plantillas de trabajo, así como material creativo de apoyo. Cada una de las tarjetas se categoriza en función de la fase de trabajo –incluyendo fases preliminares, fases de aplicación y fases de gestión-, identificando el factor o factores de creatividad que se potencian en cada una. Una descripción pormenorizada de la herramienta y teoría asociada se puede encontrar en Calavia et al. (2019); en la figura 2 se muestra el prototipo físico del kit.

El marco de trabajo para la evaluación de la herramienta se ha situado en un instituto de educación secundaria, en concreto en dos clases de 4º de la ESO, con una muestra total de 46 alumnos y 2 profesores. La herramienta se adaptó a los contenidos de la unidad didáctica “La dinámica de la Tierra” de la asignatura de Biología y Geología, que se llevó a cabo durante 6 sesiones de 50 minutos repartidas en dos semanas.

Fig. 2. Kit Aprendizaje por retos.

La estrategia metodológica ha seguido Xassess (Blanco et al., 2016), un marco teórico-práctico de evaluación de producto y servicio aplicable en cualquier punto del proceso de diseño. En este caso, Xassess se ha adaptado a la idiosincrasia del escenario de educación y enfocado a la evaluación colaborativa entre diferentes especialidades. La metodología de evaluación plantea un proceso en cinco fases que se recogen en la figura 3 y siguientes puntos.

Fig. 3. Esquema simplificado de las fases de Xassess.

When? En general, independientemente de la etapa del proyecto en la que nos encontramos, la evaluación sirve principalmente para la toma de decisiones; no obstante, Xassess describe distintos enfoques de evaluación según la fase del proyecto: necesidades, conceptualización, desarrollo, o evaluación. En el caso que se presenta, el diseño y evaluación del kit se planteó en sucesivas fases iterativas. Es necesario señalar que, a la hora de evaluar una herramienta en un entorno educativo con profesores y alumnos, ésta debe encontrarse en una fase del proyecto avanzada, con calidad suficiente para que la evaluación pueda llevarse a cabo de manera correcta, ya que en fases tempranas puede provocar desconfianza o confusión, disminuyendo la aceptación por los usuarios. En este sentido, la evaluación que se presenta en este trabajo se sitúa al final de una segunda iteración diseño-desarrollo- evaluación.

Why? Para responder esta cuestión debemos plantearnos cuáles son los objetivos generales de la evaluación, tanto desde una perspectiva general que depende en gran medida del "when", por ejemplo tomar decisiones, evaluar, seleccionar, analizar, modelar, simular, probar o experimentar (Sim & Duffy, 2003); como desde una perspectiva más concreta, que depende del producto, escenario y usuario.

En este caso, en el nivel general se sitúan los objetivos de validar el cometido de la herramienta en campo, con alumnos y profesores reales; y de obtener la retroalimentación necesaria para la mejora y la toma de decisiones, en caso necesario, para el diseño final de un producto finalista y susceptible de someterse a una evaluación más en masa. Por otro lado, en el nivel de escenario, se establecen cuestiones tales como ¿cuál es el nivel de interacción de la herramienta con usuarios reales, tanto alumnos como profesores?; ¿cómo se adapta a las características del entorno? ¿cómo contribuye al fomento de la creatividad? ¿cómo se adapta a problemas planteados desde una asignatura habitualmente no relacionada con la creatividad? ¿es apta la herramienta para su aplicación a gran escala?

Who? Xassess plantea el "who" como el análisis de los actores en una evaluación y distinguiendo entre quién es el objeto de evaluación (a quién evaluamos) y quién es el ejecutor de la evaluación (quién evalúa). Como veremos, en el caso que nos ocupa es de especial interés el hecho de que ambos niveles, a quién y quién, se fusionan en algunos puntos (fig. 4).

La evaluación del "Manual para enseñar por retos" se lleva a cabo con usuarios finales. El perfil principal de usuario corresponde al docente, usuario de la herramienta de primer nivel, ya que la interpreta y aplica. Asimismo, el docente es el encargado de introducir y aplicar las herramientas en el aula, así como de proveer de recursos a los estudiantes. Por tanto, puede actuar como usuario-proxie (Johnson, Clarkson, & Huppert, 2010). El perfil secundario es el del alumno como usuario final en calidad de usuarios que disfrutan de su aplicación.

Por su parte, la respuesta a la segunda cuestión nos permite establecer el equipo de evaluación. Xassess plantea que no solo los evaluadores, sino los equipos x-disciplinares de profesionales colaboren en la evaluación, orientando esta misma como herramienta estratégica de diseño. Es necesario que el equipo técnico entienda las restricciones y potenciales asociados al escenario, en este caso el entorno

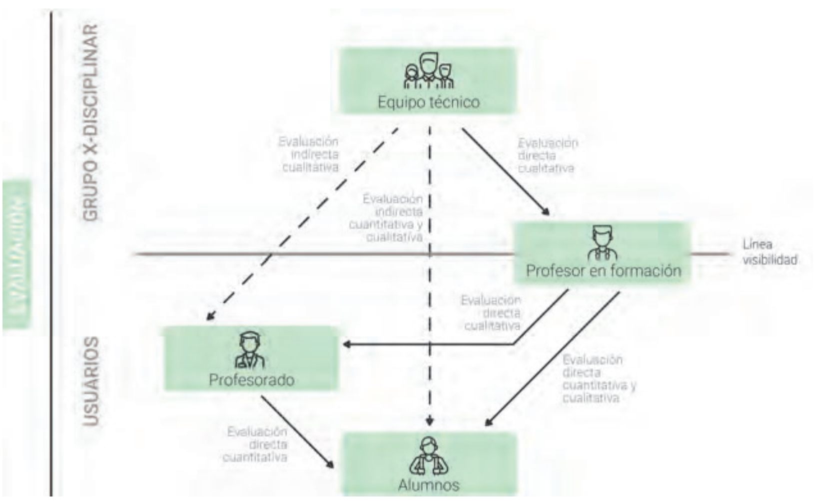


Fig. 4. Manual de enseñar por retos. Relaciones de evaluación en el who y en el how.

educativo, y el usuario, en este caso los docentes, vean la propuesta como oportunidad y no como amenaza. Visto el when y el why, que sitúan la presente evaluación como una previa a la aplicación a gran escala, se definió el siguiente perfil x-disciplinar para la evaluación:

Ingeniería-diseño: El equipo técnico encargado de diseñar y desarrollar la herramienta estaba compuesto por diseñadores provenientes de diferentes especialidades de la ingeniería (por tanto multidisciplinar en sí mismo), algunos de los cuales contaban con experiencia docente universitaria. En la evaluación, este grupo aportaba la perspectiva global de producto, experiencia en evaluación y en metodologías de trabajo entre disciplinas.

Geología: Un profesor en formación fue el encargado de aplicar la herramienta en el aula. Su perfil era idóneo, ya que correspondía a un profesional de la geología con muchos años de experiencia en la empresa, que comenzaba su actividad como profesor de instituto. Como se ve en la figura 3, su posición era compleja, porque ostentaba a la vez dos figuras: (i) como evaluador en campo, actuando como transmisor de información entre los usuarios y el equipo técnico, que no podía estar dentro del aula en el momento de aplicación; (ii) como usuario, es decir como objeto de evaluación por parte del equipo técnico, ofreciendo un perfil sensible y afín a materiales novedosos, alta motivación y frescura.

Educación: La perspectiva de evaluación se consiguió principalmente en las primeras iteraciones de evaluación, mencionadas anteriormente, donde se validaron las bases pedagógicas del kit. En la evaluación que se presenta aquí, el perfil de educación lo aportaba el profesor en formación como parte del equipo evaluador, junto con el profesor titular evaluado como usuario principal, que a su vez actuaba de evaluador cuantitativo del desempeño de los alumnos.

Cada uno de los actores del proyecto, situados tanto en uno como en otro plano (fig. 3), suele tener una visión diferente del producto. Establecer las motivaciones de cada parte (tabla. 1) proporciona una perspectiva global del proyecto, y además de ayudar a mejorar la comunicación, la relación y la valoración entre perfiles, contribuye a la definición de los indicadores de evaluación.

What? El "what" responde a aquellos aspectos del producto que deben evaluarse. Para responder esta pregunta, se comienza por el objetivo principal del recurso educativo, que coincide con el objetivo principal de validación. En el caso que se presenta, el objetivo principal de evaluación es comprobar si la herramienta contribuye en la formación de individuos más creativos.

Es cierto que existen multitud de estudios centrados en la elaboración de métricas para evaluar la creatividad (Ibáñez, 1998), analizando cómo de creativa es una persona a partir de indicadores como el número o la calidad de las ideas. Una posibilidad en la evaluación podría haber sido aplicar una de estas métricas, creando una competición entre los alumnos y consiguiendo una "calificación", pero ¿de qué sirve que un alumno tenga grandes ideas si su capacidad de comunicación y de trabajo en equipo es baja y no puede transmitirlas? ¿o si el proceso creativo no es razonado? Por ello, en este contexto no se busca "medir" la creatividad, sino los caminos que la conforman; definiendo aquellos factores que construyen al individuo creativo, que incluyen conceptos tales como flexibilidad, novedad, participación, motivación intrínseca, análisis, polinización, divergencia, autoevaluación o redefinición, entre otros (Calavia, Blanco & Casas, 2019).

Además de estos factores específicos, y uniendo el what y el who, la definición de las motivaciones de cada actor involucrado en el proyecto ayuda a definir otro tipo de indicadores a los que debe responder la herramienta (Tabla 1).

How? Xassess plantea tres estrategias de evaluación (fig. 5) y propone la triangulación o la combinación como estrategias óptimas en la fase de evaluación. En el caso que se presenta, se han seguido diferentes estrategias de combinación como de triangulación de métodos cuantitativos (con técnicas como tests, pruebas objetivas, escalas sistematizadas de observación y encuestas de satisfacción) y métodos cualitativos (técnicas de observación de usuario, entrevistas en profundidad, y grupos de discusión).

La elección de métodos y estrategias ha dependido directamente de cada uno de los indicadores en torno a la creatividad, siempre clasificados bajo dos perspectivas: la del docente y la del alumno. En la

Equipo técnico	Profesorado	Alumno
¿Es compatible con el currículo y los centros?	- ¿Es compatible con el currículo?	- ¿Me va a suponer mucho esfuerzo y tiempo fuera de las clases?
- ¿Es apropiado para profesores y alumnos?	- ¿Se adapta al tiempo y al temario asignado?	- ¿Me ayuda a comprender mejor los conceptos?
- ¿Los profesores querrán incorporarlo en sus aulas?	- ¿Me va a suponer mucho esfuerzo y tiempo?	- ¿Me permite aprender de forma diferente?
- ¿Es fácil aprender a utilizarlo?	- ¿Mi estatus como profesor va a verse modificado?	- ¿Hace que la clase sea más amena?
- ¿Facilita el aprendizaje competencial?	- ¿Voy a saber utilizarlo?	- ¿Voy a sentirme cómodo y motivado durante las clases?
- ¿Permite un aprendizaje diferente a la copia o la memoria?	- ¿Qué papel tengo que tomar durante las clases?	- ¿Me aporta habilidades nuevas además de conocimientos?
- ¿Fomenta la creatividad?	- ¿Va a alborotar a los alumnos?	- ¿Cómo va a influir en mi calificación de la asignatura?
- ¿Fomenta aspectos como la participación y la motivación?	- ¿Voy a sentirme cómodo en mis clases?	- ¿Qué va a evaluar mi profesor?
- ¿Ayuda a establecer un clima cálido de comunicación?	- ¿Qué ventajas me aporta?	
- ¿Tendrá apoyo de otras entidades?	- ¿Qué competencias potencia en mis alumnos?	
- ¿Es innovador desde el punto de vista científico?	- ¿Está planteando según bases pedagógicas?	
	- ¿Cómo realizo la calificación de mis alumnos?	

Tabla. 1. Necesidades de las partes involucradas en el proyecto.

Tabla 2 se puede ver un resumen de los objetivos e indicadores; para mayor detalle acerca de las estrategias, instrumentos y factores, véase Calavia, Blanco & Casas (2019). En general, a la hora de plantear los métodos de evaluación es importante tener en cuenta algunas restricciones, tales como el tiempo disponible y el número total de usuarios.

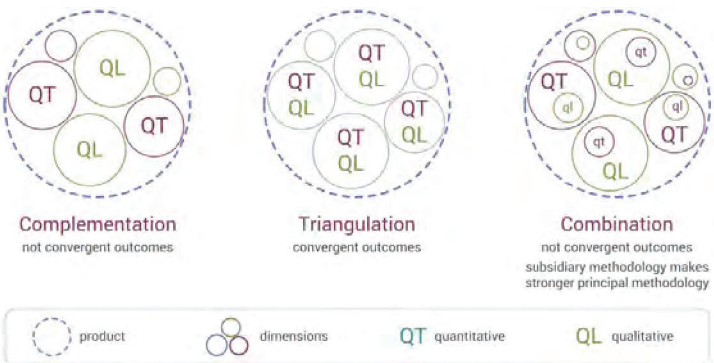


Fig. 5. Estrategias de evaluación (Blanco et al., 2016)

Objetivo de evaluación	Vis	Indicador	Objetivo de evaluación	Vis	Indicador
Incorporación al entorno	Doc	Paralelismo con objetivos currículo	Tiempos de trabajo	Doc	Tiempos de pensamiento y reflexión para el desarrollo del trabajo
		Flexibilidad herramienta			
		Dificultades en la adaptación			
Ambiente	Doc	Comunicación/participación en comparación	Adecuación del material	Doc	Percepción general
		Diálogo Doc-Al, Al-Al, Al-Doc			Visión de técnicas de diseño
		Análisis de las actitudes alumnos			Interés en utilizar la herramienta
	Al	Percepción emocional		Al	Análisis del uso del material
		Clima adecuado			Percepción general
		Nivel de participación			Comparativas otros materiales
		Nivel de participación en Comparativas otros materiales comparación			
Comprensión/ entendimient o deconceptos	Doc	Aprendizaje en geología	Motivación	Doc	Análisis de la participación
		Procesos de aprendizaje			Análisis del interés
		Calificaciones			Cantidad información recopilada
		Evolución de las calificaciones			Comparativa con casos anteriores
	Al	Percepción de aprendizaje geología		Al	Interés despertado
		Entendimiento conceptos de geología			Actitud y disposición
		Unión temario con su vida y realidad			Motivación en resolución de retos
Divergencia	Doc	Cantidad de ideas	Opinión	Doc	Opinión general clases/ herramienta
		Análisis de las ideas			Aportaciones para la mejora
		Nexo de ideas con conocimiento			Uso de la metodología en otras clases
	Al	Cantidad y calidad de sus ideas		Al	Pros-cons
Trabajo en equipo y polinización	Doc	Comunicación, coordinación y compromiso integrantes	Autoevaluación y redefinición	Doc	Autopercepción, capacidad de retroalimentación
	Al	Espíritu de equipo		Al	Autopercepción dentro del equipo
		Opinión trabajo en equipo			
		Opinión trabajo de su equipo			
		Opinión trabajo de otro equipo			

Tabla. 2. Objetivos, perfiles (docente/alumno) e indicadores

3. Resultados y discusión

Fruto del enfoque educativo actual basado en competencias, y con el objetivo de fomentar la creatividad en los entornos educativos, se ha puesto de manifiesto la necesidad de desarrollar recursos que conecten a docentes y alumnos, y trabajen desde dicho enfoque. En este marco, se ha presentado la evaluación de una nueva herramienta, Manual para enseñar por retos, que se plantea desde la perspectiva de la disciplina del diseño y desde un punto de vista x-disciplinar.

La evaluación ha confirmado que la herramienta contribuye en la formación de individuos más creativos, trabajando habilidades muy demandas en la actualidad (Tulsi & Poonia, 2015). El equipo ha procesado los resultados de forma convergente hacia la definición de nuevas especificaciones de diseño, obteniendo valiosas conclusiones para la mejora del producto. Entre otros, la posibilidad de facilitar el uso de la herramienta por el docente llevando a cabo una versión en formato digital a modo de guía, con el objetivo de que sea más intuitiva; la inclusión de materiales para mejorar la competencia de la comunicación en las presentaciones; la introducción de materiales tecnológicos para acercarse a la realidad de los alumnos; la importancia de establecer un clima determinado para que los alumnos aumenten su participación; la oportunidad del diseño en este ámbito; etc.

La perspectiva x-disciplinar ha sido clave en este sentido, contribuyendo claramente al diseño y análisis de un producto más cercano a las motivaciones y necesidades de todos y cada uno de los actores y sacando a la luz cuestiones emergentes antes no descubiertas. Sin embargo, también ha supuesto un desafío y aprendizaje, que se alinea con lo descrito en la literatura (Blanco, 2016; Kleinsmann & Valkenburg, 2008): mayores plazos en el proyecto, necesidad de aunar dialectos y matices disciplinares (actores, currículo, normativa y objetivo son vocablos habituales que han inducido a error por las diferentes interpretaciones), incluso inicialmente, las habituales desconfianzas entre especialidades (Evans & Marvin, 2004; Peeters, van Tuijl, Reymen, & Rutte, 2007); en este caso entre ciencias, educación e ingenierías. Adicionalmente, la inclusión de los usuarios y la complejidad del entorno han supuesto otro punto mixto de beneficio y dificultad; por ejemplo, las diferencias entre docentes y alumnos (edad, motivación, situación personal, actitud) o el nivel administrativo y estructural de los centros (disponibilidad de recursos, horarios restringidos, tamaño clase, limitaciones de tiempo).

Como apunte general, es interesante reivindicar el valor de la disciplina del diseño como oportunidad de innovación para todo tipo de ámbitos, por la perspectiva holística que aporta, por su capacidad como conector de disciplinas y por la adaptabilidad de sus herramientas. En esta línea, se ha confirmado la posibilidad de un camino de investigación y aportación del diseño, como medio, facilitador y motor en una innovación x-disciplinar (Blanco, 2016; Wahl & Baxter, 2008).

4. Conclusiones

En este trabajo se presenta la evaluación de una nueva herramienta, "Manual para enseñar por retos", siguiendo una metodología específica de evaluación de producto que parte desde un planteamiento de diseño x-disciplinar. La evaluación propuesta ha permitido validar el papel de herramienta como facilitador de la creatividad de los alumnos, creatividad entendida como la capacidad de resolver problemas de forma innovadora; además, ha permitido obtener retroalimentación para la mejora de la misma. La evaluación desde un punto x-disciplinar ha supuesto un esfuerzo mayor, ya que requiere de alta organización y trabajo para asegurar la conexión entre las partes; sin embargo, permite aglutinar todo el conocimiento y perspectivas tanto de las disciplinas involucradas como de los perfiles de usuario finales, obteniendo como resultado problemas imposibles de detectar dentro de un laboratorio.

Bibliografía

BLANCO, T. (2016). Metodologías De Diseño Como Plataforma Para La X-Disciplinaridad En Proyectos Tecnológicos: Surfing Disciplines. Universitat Politècnica de València. http://hdl.handle.net/10251/77149

BLANCO, T., Berbegal, A., Blasco, R., & Casas, R. (2016). Xassess: Crossdisciplinary framework in user-centred design of assistive products. J*ournal of Engineering Design, 27*(9), 636-664.

BLANCO, T., LÓPEZ-FORNIÉS, I., & ZARAZAGA-SORIA, F. J. (2017). Deconstructing the tower of babel: A design method to improve empathy and teamwork competences of informatics students. *International Journal of Technology and Design Education*, 27(2), 307-328.

BLUMENFELD, P. C., SOLOWAY, E., MARX, R. W., KRAJCIK, J. S., GUZDIAL, M., & PALINCSAR, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3-4), 369-398.

BULLEN, M., & MORGAN, T. (2016). Digital learners not digital natives. *La Cuestión Universitaria*, (7), 60-68.

BURKUS, D. (2013). *The myths of creativity: The truth about how innovative companies and people generate great ideas* John Wiley & Sons.

CALAVIA, M.B., BLANCO, T., & CASAS, R. (2019). Fostering creativity as a problem-solving competence: Learning by Challenges, a resource for teachers based on design engineering (preprint)

DALY, S. R., ADAMS, R. S., & BODNER, G. M. (2012). What does it mean to design? A qualitative investigation of design professionals' experiences. *Journal of Engineering Education, 101*(2), 187-219.

EVANS, R., & MARVIN, S. (2004). Disciplining the sustainable city: Moving beyond science, technology or society?

GALLARDO-ECHENIQUE, E. E., MARQUÉS-MOLÍAS, L., BULLEN, M., & STRIJBOS, J. (2015). Let's talk about digital learners in the digital era. *The International Review of Research in Open and Distributed Learning,16*(3)

GISBERT, M., & ESTEVE, F. (2016). Digital leaners: La competencia digital de los estudiantes universitarios. *La Cuestión Universitaria*, (7), 48-59.

HENRIKSEN, D., RICHARDSON, C., & MEHTA, R. (2017). Design thinking: A creative approach to educational problems of practice. *Thinking Skills and Creativity, 26*, 140-153.

IBÁÑEZ, R. M. (1998). *La creatividad: Diagnóstico, evaluación e investigación* Uned.

JENKINS, H., PURUSHOTMA, R., WEIGEL, M., CLINTON, K., & ROBISON, A. J. (2009). C*onfronting the challenges of participatory culture: Media education for the 21st century* Mit Press.

JOHNSON, D., CLARKSON, J., & HUPPERT, F. (2010). Capability measurement for inclusive design. *Journal of Engineering Design*, 21(2-3), 275-288.

KLEIMAN, P. (2008). Towards transformation: Conceptions of creativity in higher education. *Innovations in Education and Teaching International, 45*(3), 209-217.

KLEINSMANN, M., & VALKENBURG, R. (2008). Barriers and enablers for creating shared understanding in co-design projects. *Design Studies, 29*(4), 369-386.

LEE, M., & ERDOGAN, I. (2007). The effect of science–technology–society teaching on students' attitudes toward science and certain aspects of creativity. *International Journal of Science Education, 29*(11), 1315-1327.

LÓPEZ MARTÍNEZ, O. (2008). Enseñar creatividad: El espacio educativo. C*uadernos de la Facultad de Humanidades Y Ciencias Sociales.Universidad Nacional De Jujuy*, (35), 61-75.

NORMAN, D. A., & VERGANTI, R. (2014). Incremental and radical innovation: Design research vs. technology and meaning change. *Design Issues, 30*(1), 78-96.

PAGE, T., & THORSTEINSSON, G. (2017). Teaching creativity across the curriculum through design education? *I-Manager's Journal of Educational Technology, 14*(1), 7.

PEETERS, M. A., VAN TUIJL, H. F., REYMEN, I. M., & RUTTE, C. G. (2007). The development of a design behaviour questionnaire for multidisciplinary teams. *Design Studies, 28*(6), 623-643.

SIM, S. K., & DUFFY, A. H. (2003). Towards an ontology of generic engineering design activities. *Research in Engineering Design, 14*(4), 200-223.

THORSTEINSSON, G., & PAGE, T. (2017). Teaching creativity across the curriculum through design education. case studies. *Educatia 21*, (15), 13-22.

TULSI, P., & POONIA, M. (2015). Expectations of industry from technical graduates: Implications for curriculum and instructional processes. *Journal of Engineering Education Transformations*, 19-24.

TUNING, P. (2003). Tuning educational structures in europe. *Informe Final.Proyecto Piloto.Fase, 1*, 2004-2007.

WAHL, D. C., & BAXTER, S. (2008). The designer's role in facilitating sustainable solutions. *Design Issues, 24*(2), 72-83.

WILHELM, W. J., LOGAN, J., SMITH, S. M., & SZUL, L. F. (2002). Meeting the demand: Teaching" soft" skills.

WONG, Y. L., & SIU, K. W. M. (2012). A model of creative design process for fostering creativity of students in design education. *International Journal of Technology and Design Education, 22*(4), 437-450.

3.4. Estudio 4

Calavia, M. B., Blanco, T., Casas, R., & Dieste, B. (2022). Making Design Thinking for Education sustainable: Training preservice teachers to address practice challenges. *Thinking skills and creativity,* 101199.

https://doi.org/10.1016/j.tsc.2022.101199

BD: JCR | FI: 3.652 | Q: *Education & Educational Research* (Q1 - 63/270)

Thinking Skills and Creativity 47 (2023) 101199

Contents lists available at ScienceDirect

Thinking Skills and Creativity

journal homepage: www.elsevier.com/locate/tsc

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

M. Belén Calavia [a,b], Teresa Blanco [a,c,d,*], Roberto Casas [a,e], Belén Dieste [f,g]

[a] Howlab - Human Openware Research Group., Aragon Institute of Engineering Research (I3A), University of Zaragoza, Zaragoza, Spain
[b] Department of Design and Manufacturing Engineering, University of Zaragoza, Zaragoza, Spain
[c] Department of Musical, Plastic and Body Language Expression, University of Zaragoza, Zaragoza, Spain
[d] GeoSpatiumLab S.L., C/Carlos Marx, 6, 50015 Zaragoza, Spain
[e] Department of Electronic Engineering, University of Zaragoza, Zaragoza, Spain
[f] Department of Education Sciences, University of Zaragoza, Zaragoza, Spain
[g] Education and Diversity Research Group, University of Zaragoza, Zaragoza, Spain

ARTICLE INFO

Keywords:
Design thinking
Teaching skills
Methodology
Preservice teachers
Instructional materials

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;

* Corresponding author at: Howlab - Human Openware Research Group. Aragon Institute of Engineering Research (I3A), University of Zaragoza, C/Mariano Esquillor, s/n, 50018 Zaragoza, Spain.
E-mail address: tblanco@unizar.es (T. Blanco).

https://doi.org/10.1016/j.tsc.2022.101199
Received 20 December 2021; Received in revised form 17 October 2022; Accepted 24 November 2022
Available online 28 November 2022
1871-1871/

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 oversimplification 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).

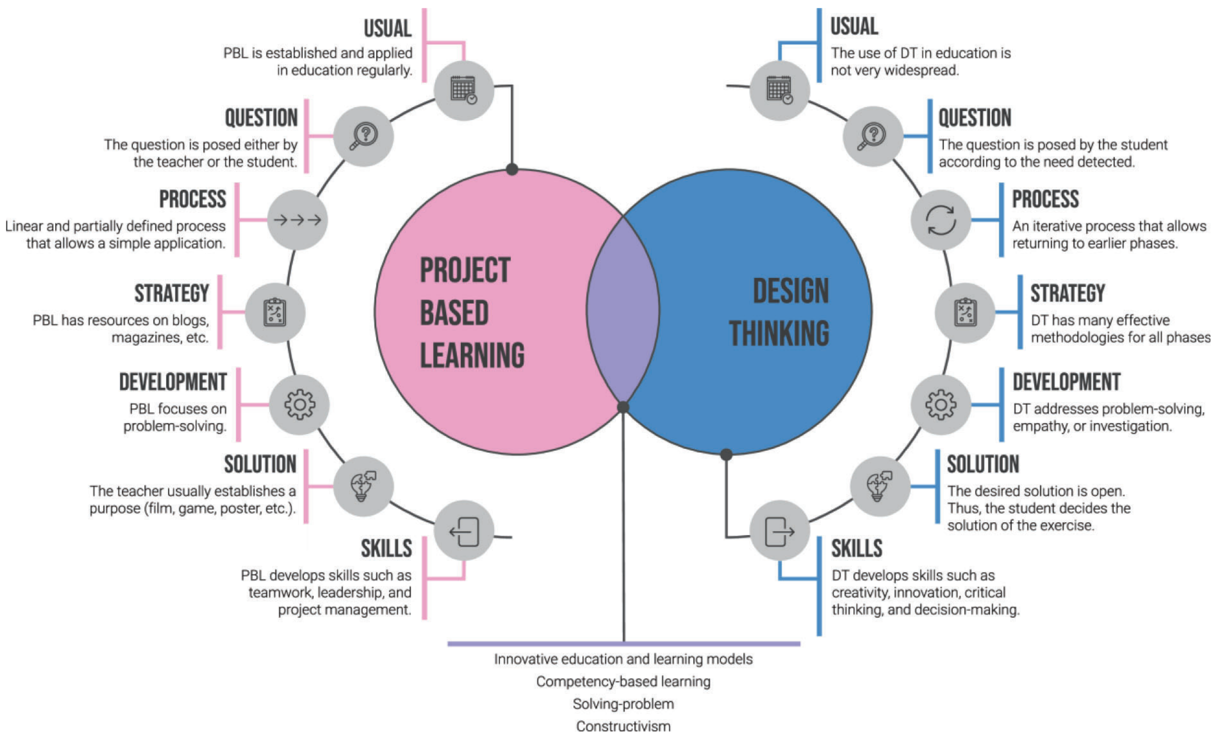


Fig. 1. Characteristics, differences, and similarities between PjBL and DT.

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

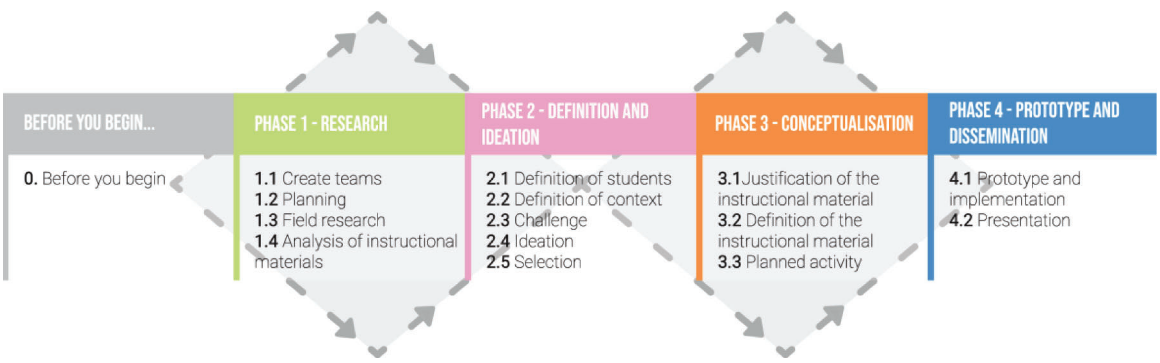


Fig. 2. Phases and cards of the 'Think-Create-Teach' (TCT) methodology.

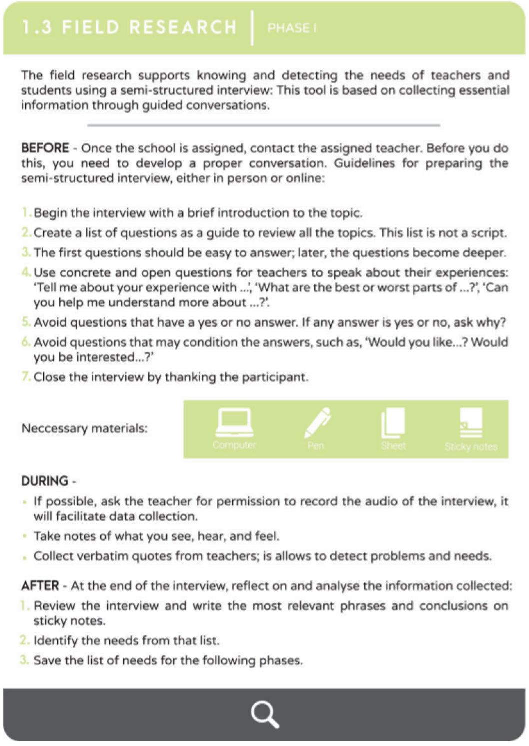


Fig. 3. Example card of the TCT methodology (1.3 Field research).

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

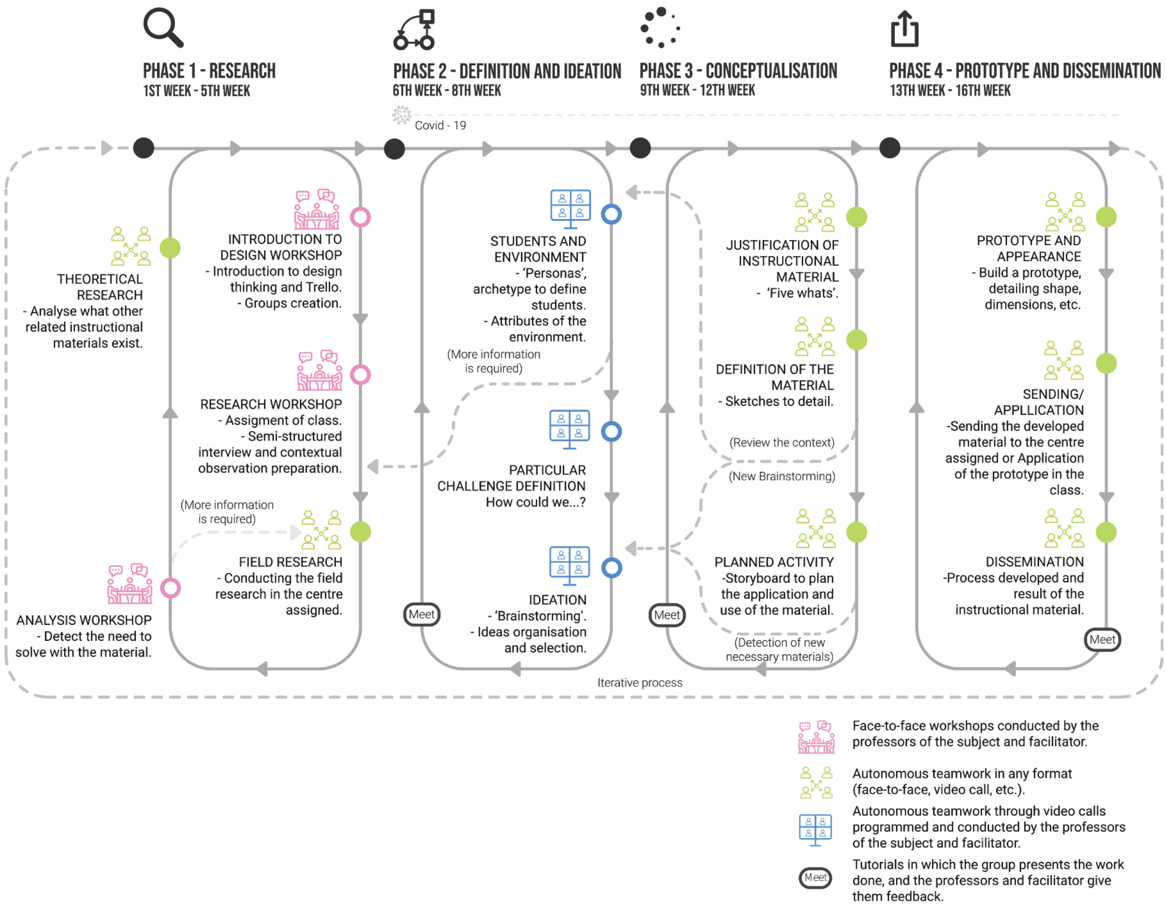


Fig. 4. TCT application process.

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

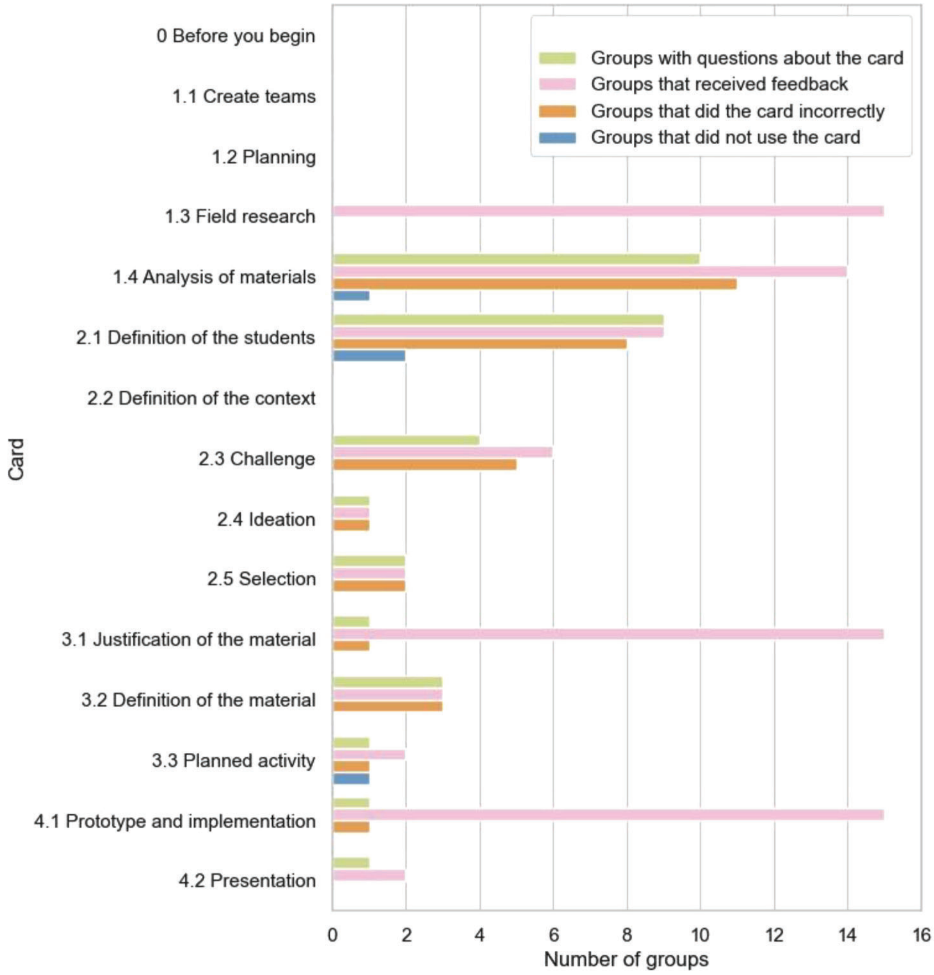


Fig. 5. Assessment of the card execution, from 0 (none) to 15 (all).

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.

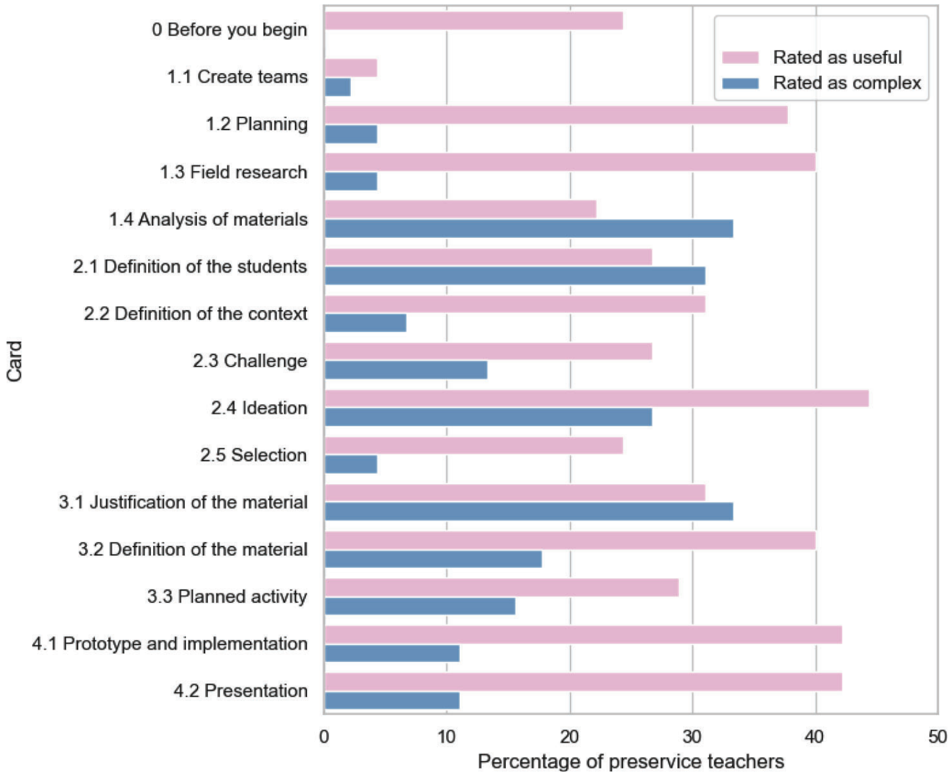


Fig. 6. Assessment of the usefulness and complexity of the cards. From 0 (no preservice teacher selected the card) to 56 (all preservice teachers selected the card).

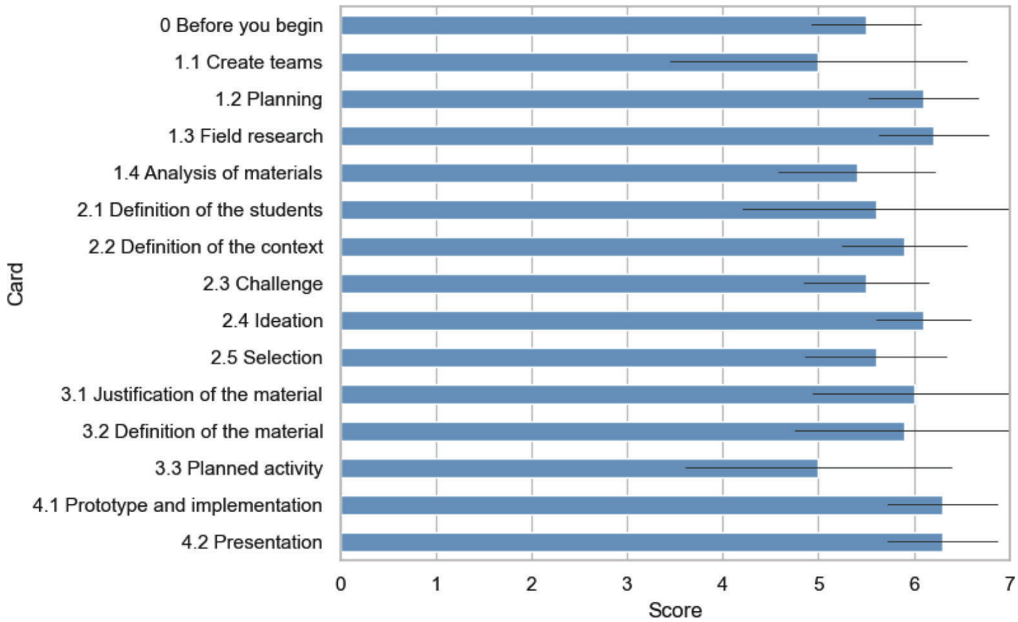


Fig. 7. Card valuations reported by preservice teachers (mean and standard deviation detailed in Table 4). Scores range from 0 (minimum valuation) to 7 (maximum valuation).

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

Card	Score	P-value - Wilcoxon test													
	μ ± σ	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.

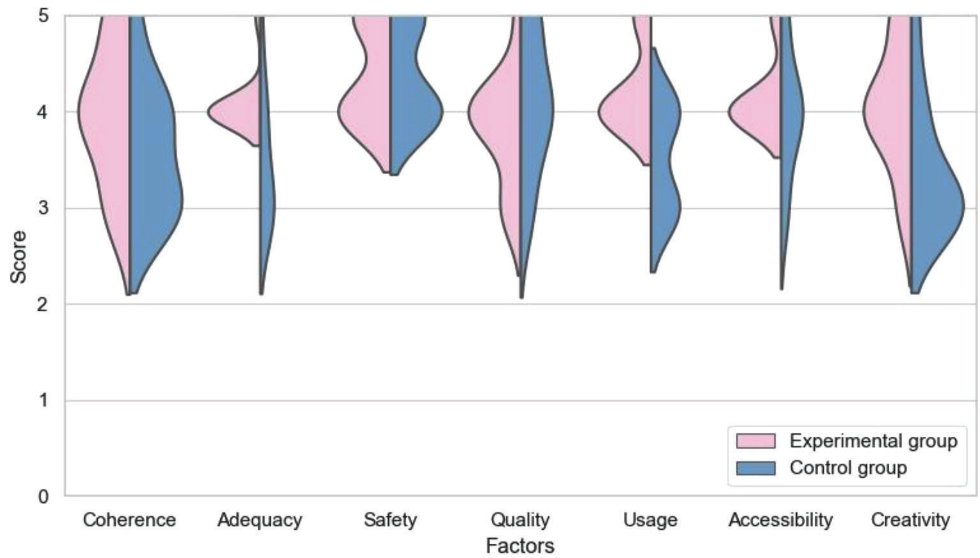


Fig. 8. Assessment of instructional material (mean and standard deviation detailed in Table 6). Comparison between the experimental group and the control group. Scores range from 0 (minimum valuation) to 5 (maximum valuation).

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.

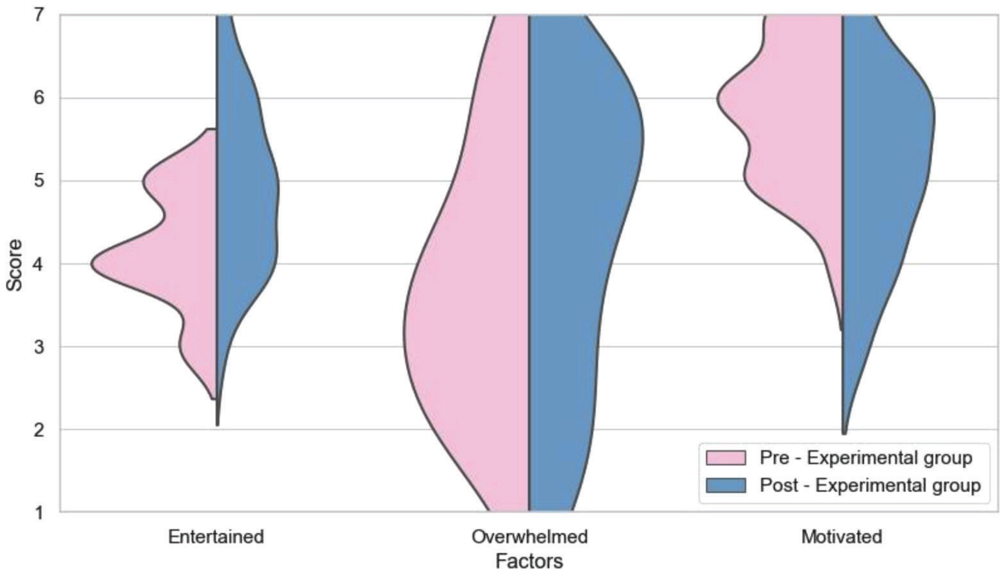


Fig. 9. Assessment of emotional responses (mean and standard deviation detailed in Table 7). Comparison between pre- and post-course. Scores range from 0 (minimum valuation) to 7 (maximum valuation).

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.

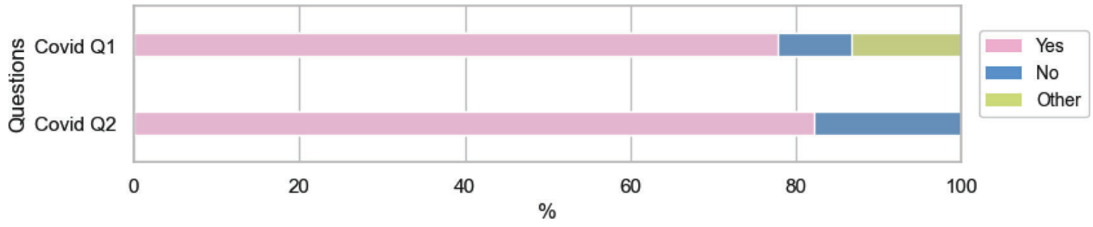


Fig. 10. Covid-19 special situation.

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.

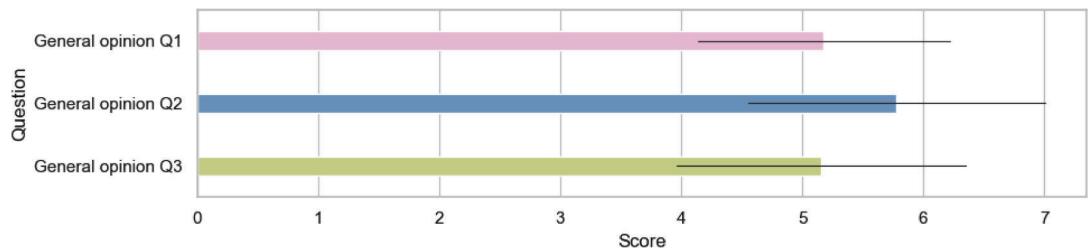


Fig. 11. Perceived contribution score (mean and standard deviation detailed in Table 8). From 0 (minimum valuation) to 7 (maximum valuation).

Table 8
Statistical results of the general opinion.

Questions	Score $\mu \pm \sigma$	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.

Funding

This work was partially supported by the Government of Aragon, under Grant BOA20180615027, and under Grant T27_17R; and by the Spanish MINECO under Grant PTQ2018-010045.

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.

Acknowledgements

We would like to thank the teachers and preservice teachers who participated in this study. This project would not have been possible without their participation and their feedback. Finally, we would like to thank the Government of Aragon and the Spanish MINECO for the financial support.

References

Achtenhagen, F. (2001). Criteria for the development of complex teaching-learning environments. *Instructional Science, 29*(4-5), 361–380.
Adair, J. G. (1984). The hawthorne effect: A reconsideration of the methodological artifact. *Journal of Applied Psychology, 69*(2), 334.
Ahmadi, N., Peter, L., Lubart, T., & Besançon, M. (2019). School environments: Friend or foe for creativity education and research? In C. A. Mullen (Ed.), *Creativity under duress in education?* (Ed., pp. 255–266). Springer.
Armstrong, R. A. (2014). When to use the B onferroni correction. *Ophthalmic and Physiological Optics, 34*(5), 502–508.
Bain, K. (2005). *Lo que hacen los mejores profesores universitarios*. Universidad de Valencia.
Bennett, S., Agostinho, S., & Lockyer, L. (2017). The process of designing for learning: Understanding university teachers' design work. *Educational Technology Research and Development, 65*(1), 125–145.
Blanco, T., Berbegal, A., Blasco, R., & Casas, R. (2016). Xassess: Crossdisciplinary framework in user-centred design of assistive products. *Journal of Engineering Design, 27*(9), 636–664.
Blanco, T., Casas, R., Manchado-Pérez, E., Asensio, Á., & López-Pérez, J. M.. (2017a). From the islands of knowledge to a shared understanding: Interdisciplinarity and technology literacy for innovation in smart electronic product design. *International Journal of Technology and Design Education, 27*(2), 329–362.
Blanco, T., López-Forniés, I., & Zarazaga-Soria, F. J.. (2017b). Deconstructing the tower of babel: A design method to improve empathy and teamwork competences of informatics students. *International Journal of Technology and Design Education, 27*(2), 307–328.
Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3-4), 369–398.
Brown, T. (2008). Design thinking. *Harvard Business Review, 86*(6), 84.
Brown, T., & Wyatt, J. (2010). Design thinking for social innovation. *Development Outreach, 12*(1), 29–43.
Bullen, M., & Morgan, T. (2016). *Digital learners not digital natives, 7* pp. 60–68). La Cuestión Universitaria.
Calavia, M. B., Blanco, T., & Casas, R. (2019). Formando a personas creativas en la era digital. Evaluación x-disciplinar de una herramienta basada en el diseño. In C. Foradada, & P. Irala-Hortal (Eds.), *Re_Visiones sobre arte, patrimonio y tecnología en la era digital* (p. 185). Gobierno de Aragón.

Calavia, M. B., Blanco, T., & Casas, R. (2021). Fostering creativity as a problem-solving competence through design: Think-Create-Learn, a tool for teachers. *Thinking skills and creativity, 39*, Article 100761. https://doi.org/10.1016/j.tsc.2020.100761

Calavia, M. B., Blanco, T., Casas, R., & Dieste, B. (2022). Improving Design Project Management in Remote Learning. *Sustainability, 14*(17), Article 11025. https://doi.org/10.3390/su141711025

Carroll, M., Goldman, S., Britos, L., Koh, J., Royalty, A., & Hornstein, M. (2010). Destination, imagination and the fires within: Design thinking in a middle school classroom. *International Journal of Art & Design Education, 29*(1), 37–53.

Carroll, M. P. (2014). *Shoot for the moon! the mentors and the middle schoolers explore the intersection of design thinking and STEM, 4* p. 3). Journal of Pre-College Engineering Education Research (J-PEER.

Chang, L., & Lee, G. C. (2010). A team-teaching model for practicing project-based learning in high school: Collaboration between computer and subject teachers. *Computers & Education, 55*(3), 961–969.

Coleman, M. C. (2016). Design thinking and the school library. *Knowledge Quest, 44*(5), 62–68.

Collard, P., & Looney, J. (2014). Nurturing creativity in education. *European Journal of Education, 49*(3), 348–364.

Cross, N. (2011). *Design thinking: Understanding how designers think and work*. Berg.

Dag, F., & Durdu, L. (2017). Pre-service teachers' experiences and views on project-based learning processes. *International Education Studies, 10*(7), 18–39.

Daly, S. R., Adams, R. S., & Bodner, G. M. (2012). What does it mean to design? A qualitative investigation of design professionals' experiences. *Journal of Engineering Education, 101*(2), 187–219.

Delgado, A., Mesquida, A. L., & Mas, A. (2014). Utilización de trello para realizar el seguimiento del aprendizaje de equipos de trabajo. In *Proceedings of the XX* (pp. 53–58). Jornadas de Enseñanza Universitaria de la Informática.

Diaper, G. (1990). The hawthorne effect: A fresh examination. *Educational Studies, 16*(3), 261–267.

Dorst, K. (2010). The nature of design thinking. In *Proceedings of the 8th Design Thinking Research Symposium* (pp. 131–139).

Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problem-solution. *Design Studies, 22*(5), 425–437.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103–120.

Elwood, K., Savenye, W., Jordan, M. E., Larson, J., & Zapata, C. (2016). Design thinking: A new construct for educators. In *Proceedings of the Annual Convention of the Association of Educational Communications and Technology* (pp. 43–52).

Freeman, A., Becker, S. A., & Cummins, M. (2017). *NMC/CoSN Horizon Report: 2017 K-12 Edition*. Austin, TX: The New Media Consortium.

Gallardo-Echenique, E. E., Marqués-Molías, L., Bullen, M., & Strijbos, J. (2015). *Let's talk about digital learners in the digital era, 16*. The International Review of Research in Open and Distributed Learning.

Geisinger, K. F. (2016). 21st century skills: What are them and how do we assess them? *Applied Measurement in Education, 29*(4), 245–249.

Gisbert, M., & Esteve, F. (2016). Digital leaners: La competencia digital de los estudiantes universitarios. *La Cuestión Universitaria*, (7), 48–59.

Gleason, B., & Cherrez, N. J. (2021). Design thinking approach to global collaboration and empowered learning: Virtual exchange as innovation in a teacher education course. *TechTrends, 65*(3), 348–358.

Goldman, S., & Zielezinski, M. B. (2016). Teaching with design thinking: Developing new vision and approaches to twenty-first century learning. In L. A. Annetta, & J. Minogue (Eds.), *Connecting science and engineering education practices in meaningful ways* (Eds, pp. 237–262). Springer.

Grammenos, D., & Antona, M. (2018). Future designers: Introducing creativity, design thinking & design to children. *International Journal of Child-Computer Interaction, 16*, 16–24.

Gu, X., Dijksterhuis, A., & Ritter, S. M. (2019). Fostering children's creative thinking skills with the 5-I training program. *Thinking Skills and Creativity, 32*, 92–101.

Guo, J., & Woulfin, S. (2016). Twenty-first century creativity: An investigation of how the partnership for 21st century instructional framework reflects the principles of creativity. *Roeper Review, 38*(3), 153–161.

Hadar, L. L., & Tirosh, M. (2019). Creative thinking in mathematics curriculum: An analytic framework. *Thinking Skills and Creativity, 33*, Article 100585.

Häkkinen, P., Järvelä, S., Mäkitalo-Siegl, K., Ahonen, A., Näykki, P., & Valtonen, T. (2017). Preparing teacher-students for twenty-first-century learning practices (PREP 21): A framework for enhancing collaborative problem-solving and strategic learning skills. *Teachers and Teaching, 23*(1), 25–41.

Henriksen, D., Mishra, P., & Fisser, P. (2016). Infusing creativity and technology in 21st century education: A systemic view for change. *Educational Technology & Society, 19*(3), 27–37.

Henriksen, D., Richardson, C., & Mehta, R. (2017). Design thinking: A creative approach to educational problems of practice. *Thinking Skills and Creativity, 26*, 140–153.

Hernández-Leo, D., Agostinho, S., Beardsley, M., Bennet, S., & Lockyer, L. (2017). Helping teachers to think about their design problem: A pilot study to stimulate design thinking. In *Proceedings of the 9th International Conference on Education and New Learning Technologies* (pp. 5681–5690).

Hoogveld, A. W., Paas, F., & Jochems, W. M. (2005). Training higher education teachers for instructional design of competency-based education: Product-oriented versus process-oriented worked examples. *Teaching and Teacher Education, 21*(3), 287–297.

Howard, T. J., Culley, S. J., & Dekoninck, E. (2008). Describing the creative design process by the integration of engineering design and cognitive psychology literature. *Design Studies, 29*(2), 160–180.

Jenkins, H., Purushotma, R., Weigel, M., Clinton, K., & Robison, A. J. (2009). *Confronting the challenges of participatory culture: Media education for the 21st century*. The Mit Press.

Jordan, M. E. (2016). Teaching as designing: Preparing pre-service teachers for adaptive teaching. *Theory into Practice, 55*(3), 197–206.

Kali, Y., McKenney, S., & Sagy, O. (2015). Teachers as designers of technology enhanced learning. *Instructional Science, 43*(2), 173–179.

Kali, Y., & Ronen-Fuhrmann, T. (2011). Teaching to design educational technologies. *International Journal of Learning Technology, 6*(1), 4–23.

Kerr, S. T. (1981). How teachers design their materials: Implications for instructional design. *Instructional Science, 10*(4), 363–378.

Kirschner, P. A. (2015). Do we need teachers as designers of technology enhanced learning? *Instructional Science, 43*(2), 309–322.

Kleon, A. (2016). *Aprende a promocionar tu trabajo: 10 recursos para artistas, diseñadores y creativo*. Gustavo Gili.

Koehler, M. J., & Mishra, P. (2005). Teachers learning technology by design. *Journal of Computing in Teacher Education, 21*(3), 94–102.

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools, 19*(3), 267–277.

Laurillard, D. (2013). *Teaching as a design science: Building pedagogical patterns for learning and technology*. Routledge.

Lee, M., & Erdogan, I. (2007). The effect of science–technology–society teaching on students' attitudes toward science and certain aspects of creativity. *International Journal of Science Education, 29*(11), 1315–1327.

Lindberg, T., Meinel, C., & Wagner, R. (2011). Design thinking: A fruitful concept for it development? In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design thinking* (Eds., pp. 3–18). Springer.

Lindberg, T., Noweski, C., & Meinel, C. (2010). Evolving discourses on design thinking: How design cognition inspires meta-disciplinary creative collaboration. *Technoetic Arts: A Journal of Speculative Research, 8*(1).

Lodico, M. G., Spaulding, D. T., & Voegtle, K. H. (2010). *Methods in educational research: From theory to practice, 28*. John Wiley & Sons.

Lombardi, M. M. (2007). Authentic learning for the 21st century: An overview. *Educause Learning Initiative, 1*(2007), 1–12.

López, M. J. D., & Rial, R. F. (2015). *Criterios para el análisis y elaboración de materiales didácticos coeducativos para la educación infantil* (pp. 105–124). RELAdEI.Revista Latinoamericana De Educación Infantil.

López, O. (2008). *Enseñar creatividad: El espacio educativo* (pp. 61–75). Cuadernos De La Facultad De Humanidades y Ciencias Sociales.Universidad Nacional De Jujuy.

Lor, R. (2017). Design thinking in education: A critical review of literature. In *Proceedings of the International academic conference on social sciences and management /Asian conference on education and psychology* (pp. 37–68).

Lucas, F. M. M. (2015). *Función pedagógica de los recursos materiales en educación infantil* (pp. 12–25). Vivat Academia.

Luka, I. (2014). Design thinking in pedagogy. *The Journal of Education*, (2), 63–74. *Culture, and Society*.

Marín, J., Blanco, T., Marín, J. J., Moreno, A., Martitegui, E., & Aragüés, J. C. (2019). Integrating a gait analysis test in hospital rehabilitation: A service design approach. *PloS one, 14*(10), Article e0224409. https://doi.org/10.1371/journal.pone.0224409
Martin, R., & Martin, R. L. (2009). *The design of business: Why design thinking is the next competitive advantage*. Harvard Business Press.
Martínez, M. C., Manzano, M. J. R., Lema, L. E. C., & Andrade, L. C. V. (2019). Formación por competencias: Reto de la educación superior. *Revista De Ciencias Sociales, 25*(1), 94–101.
Design Council. (2020). The 'double diamond' design process model. Retrieved from: https://www.designcouncil.org.uk/our-work/news-opinion/double-diamond-universally-accepted-depiction-design-process. Accessed June 7, 2020.
McIntosh, E. (2012). What's the difference between PBL and design thinking? Retrieved from https://medium.com/notosh/whats-the-difference-between-pbl-and-design-thinking-32ea04c46116 Accessed June 7, 2020.
McKenney, S., Kali, Y., Markauskaite, L., & Voogt, J. (2015). Teacher design knowledge for technology enhanced learning: An ecological framework for investigating assets and needs. *Instructional Science, 43*(2), 181–202.
McKilligan, S., Fila, N., Rover, D., & Mina, M. (2017). Design thinking as a catalyst for changing teaching and learning practices in engineering. In *Proceedings of the 2017 IEEE Frontiers in Education Conference* (pp. 1–5).
McMullan, M. J. (2016). How using technology enhanced learning could help modernise traditional large group teaching or lecturing. *International Journal of Innovative Research in Medical Science, 1*(6), 220–231.
Melles, G., Anderson, N., Barrett, T., & Thompson-Whiteside, S. (2015). Problem finding through design thinking in education. In P. Blessinger, & J. M. Carfora (Eds.), *Inquiry-based learning for multidisciplinary programs: A conceptual and practical resource for educators* (Eds, pp. 191–209). Emerald Group Publishing Limited.
Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054.
Mishra, P., & Mehta, R. (2017). What we educators get wrong about 21st-century learning: Results of a survey. *Journal of Digital Learning in Teacher Education, 33*(1), 6–19.
Mosely, G., Wright, N., & Wrigley, C. (2018). Facilitating design thinking: A comparison of design expertise. *Thinking Skills and Creativity, 27*, 177–189.
Naghshbandi, S. (2020). Exploring the impact of experiencing design thinking on teachers' conceptualizations and practices. *TechTrends, 64*, 868–877.
Nakano, T. D. C., & Wechsler, S. M. (2018). Creativity and innovation: Skills for the 21st century. *Estudos De Psicologia (Campinas), 35*(3), 237–246.
Nguyen, K. A., DeMonbrun, R. M., Borrego, M. J., Prince, M. J., Husman, J., Finelli, C. J., & Waters, C. (2017). The variation of nontraditional teaching methods across 17 undergraduate engineering classrooms. In *Proceedings of the 2017 American Society of Engineering Education Annual Meeting*.
Noguera, I., Guerrero-Roldán, A., & Masó, R. (2018). Collaborative agile learning in online environments: Strategies for improving team regulation and project management. *Computers & Education, 116*, 110–129.
Norton, P., & Hathaway, D. (2015). In search of a teacher education curriculum: Appropriating a design lens to solve problems of practice. *Educational Technology*, 3–14.
Oakley, B., Felder, R., Brent, R., & Elhajj, I. (2004). Coping with hitchhikers and couch potatoes on teams. *Journal of Student Centered Learning, 2*(1), 32–34.
Page, T., & Thorsteinsson, G. (2017). Teaching creativity across the curriculum through design education? *Journal of Educational Technology, 14*(1), 7–19.
Pande, M., & Bharathi, S. V. (2020). Theoretical foundations of design thinking–A constructivism learning approach to design thinking. *Thinking Skills and Creativity, 36*, Article 100637.
Patton, M. Q. (2014). *Qualitative research & evaluation methods: Integrating theory and practice*. Sage publications.
Ponterotto, J. G. (2005). Qualitative research training in counseling psychology: A survey of directors of training. *Teaching of Psychology, 32*(1), 60–62.
Pruitt, J., & Grudin, J. (2003). Personas: practice and theory. In *Proceedings of the 2003 conference on Designing for user experiences* (pp. 1–15).
Qi, J. (2017). An optimization approach for flipped classroom and multimedia teaching innovation by contrast with traditional teaching. *Boletín Técnico, 55*(8). *ISSN: 0376-723X*.
Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important? *Review of Educational Research, 82*(3), 330–348.
Sancho-Gil, J. M., & Hernández-Hernández, F. (2018). *La profesión docente en la era del exceso de información y la falta de sentido*. Revista De Educación a Distancia (RED).
Scheer, A., Noweski, C., & Meinel, C. (2012). Transforming constructivist learning into action: Design thinking in education. *Design and Technology Education: An International Journal, 17*(3).
Schraw, G., & Lehman, S. (2001). Situational interest: A review of the literature and directions for future research. *Educational Psychology Review, 13*(1), 23–52.
Serrat, O. (2017). The five whys technique. *Knowledge solutions* (pp. 307–310). Singapore: Springer.
Stanford University Institute of Design. (2020). Our point of view. Retrieved from http://dschool.stanford.edu/our-point-of-view/#design-thinking Accessed June 7, 2020.
Sternberg, R. J., & Lubart, T. I. (1997). *La creatividad en una cultura conformista: Un desafío a las masas*. Paidós.
Stevenson, M., Bower, M., Falloon, G., Forbes, A., & Hatzigianni, M. (2019). By design: Professional learning ecologies to develop primary school teachers' makerspaces pedagogical capabilities. *British Journal of Educational Technology, 50*(3), 1260–1274.
Stokholm, M. (2014). Problem based learning versus design thinking in team based project work. In *Proceedings of the 16th International Conference on Engineering and Product Design Education (E&PDE14), Design Education and Human Technology Relations, the Netherlands* (pp. 268–274).
Teal, R. (2010). Developing a (non-linear) practice of design thinking. *International Journal of Art & Design Education, 29*(3), 294–302.
Toomey, E., Matthews, J., & Hurley, D. A. (2017). Using mixed methods to assess fidelity of delivery and its influencing factors in a complex self-management intervention for people with osteoarthritis and low back pain. *Brithish Medical Journal Open, 7*(8), Article e015452.
Torra, I., de Corral, I., Pérez, M. J., Triadó, X., Pagès, T., Valderrama, E., Màrquez, M. D., Sabaté, S., Solà, P., Hernàndez, C., Sangrà, A., Guàrdia, G., Estebanell, M., Patiño, J., González, A., Fandos, M., Ruiz, N., Iglesias, M. C.y, & Tena, A. (2012). Identificación de competencias docentes que orienten el desarrollo de planes de formación dirigidos a profesorado universitario. *Revista De Docencia Universitaria, 10*(2), 21–56.
Tsybulsky, D., & Muchnik-Rozanov, Y. (2019). The development of student-teachers' professional identity while team-teaching science classes using a project-based learning approach: A multi-level analysis. *Teaching and Teacher Education, 79*, 48–59.
Tulsi, P., & Poonia, M. (2015). Expectations of industry from technical graduates: Implications for curriculum and instructional processes. *Journal of Engineering Education Transformations, 28*(4), 19–24.
Uebe, A. F., Alves, A. C., & Torres, R. B. (2019). Trello as virtual learning environment and active learning organiser for PBL classes: An analysis under bloom's taxonomy. In *Proceedings of the PAEE/ALE'2019, 11th International Symposium on Project Approaches in Engineering Education (PAEE) and 16th Active Learning in Engineering Education Workshop (ALE)* (pp. 245–252).
Van der Lelie, C. (2006). The value of storyboards in the product design process. *Personal and ubiquitous computing, 10*(2), 159–162.
Vigo, M. B., & Soriano, J. (2014). Prácticas de enseñanza y aprendizaje creativo para una educación inclusiva en la formación inicial del profesorado: Experiencias de investigación. *Revista De Educación Inclusiva, 7*(1), 30–45.
Wilhelm, W. J., Logan, J., Smith, S. M., & Szul, L. F. (2002). In *Meeting the demand: Teaching" soft" skills*. Delta Pi Epsilon Publishers.
Wright, N., & Wrigley, C. (2017). Broadening design-led education horizons: Conceptual insights and future research directions. *International Journal of Technology and Design Education, 29*(1), 1–23.
Zhang, W., & Guo, A. (2017). Research on the blended teaching mode for computer network course. In *Proceedings of the 4th International Conference on Social Science and Humanity* (pp. 45–49).
Zhao, J., & Meng, Z. (2015). *Information transfer technique in classroom interaction* (p. 357). US-China Foreign Language.
Blanco, T. (2016). *Metodologías de diseño como plataforma para la x-disciplinaridad en proyectos tecnológicos: Surfing disciplines* (Doctoral dissertation, Universitat Politècnica de València, Valencia, Spain). Retrieved from https://riunet.upv.es/handle/10251/77149?show=full.

3.5. Estudio 5

Calavia, M. B., Blanco, T., Casas, R., & Dieste, B. (2022). Improving Design Project Management in Remote Learning. *Sustainability, 14*(17), 11025.
https://doi.org/10.3390/su141711025

BD: JCR | FI: 3.889 | Q: *Environmental Sciences* (Q2 - 133/279)

Q: *Environmental Studies* (Q2 - 57/128)

Q: *Green & Sustainable Science & Technology* (Q4 - 7/9)

Q: *Green & Sustainable Science & Technology* (Q3 - 35/47)

sustainability

MDPI

Article

Improving Design Project Management in Remote Learning

María Belén Calavia [1,2], Teresa Blanco [1,3,4,*], Roberto Casas [1,5] and Belén Dieste [6,7]

1 Howlab—Human Openware Research Group, Aragon Institute of Engineering Research (I3A), University of Zaragoza, C/Mariano Esquillor, s/n, 50018 Zaragoza, Spain
2 Department of Design and Manufacturing Engineering, University of Zaragoza, C/María Luna, 3, 50018 Zaragoza, Spain
3 Department of Musical, Plastic and Body Language Expression, University of Zaragoza, C/Pedro Cerbuna, 12, 50009 Zaragoza, Spain
4 GeoSpatiumLab S.L., C/Carlos Marx, 6, 50015 Zaragoza, Spain
5 Department of Electronic Engineering, University of Zaragoza, C/María Luna, 1, 50018 Zaragoza, Spain
6 Department of Education Sciences, University of Zaragoza, C/Pedro Cerbuna, 12, 50009 Zaragoza, Spain
7 Education and Diversity Research Group, University of Zaragoza, C/Pedro Cerbuna, 12, 50009 Zaragoza, Spain
* Correspondence: tblanco@unizar.es; Tel.: +34-876555464

Abstract: Design Thinking has the potential to train the soft skills of preservice teachers who will need to continuously design their future towards sustainable education. However, Design Thinking is intrinsically complex, and managing its learning and projects with large groups is not straightforward, especially in remote situations such as COVID-19. From collaborative work among disciplines, this study introduces a Design Thinking-based board to improve the implementation and management of remote design projects. This board was applied with university-level preservice teachers who worked in teams to design instructional materials for preschool. We assessed the perception of the usefulness of the board by the preservice teachers and the teachers responsible for their training, using mixed methods in two consecutive courses. The board was perceived as helpful in developing design projects and improving collaborative learning. It was beneficial for the management, monitoring, and communication, enriching the project process and outcomes. From the achieved learning, we provide guidelines for designing and using these boards to aid educators and researchers in integrating Design Thinking and developing practical and sustainable solutions. This study contributes to the natural integration of Design Thinking and technology in preservice teachers' education with a replicable and flexible process, improving the quality of education for future generations.

Keywords: improving teaching soft skills; design thinking for education; preservice teachers training; Trello; collaborative learning; COVID-19

Citation: Calavia, M.B.; Blanco, T.; Casas, R.; Dieste, B. Improving Design Project Management in Remote Learning. *Sustainability* **2022**, *14*, 11025. https://doi.org/10.3390/su141711025

Academic Editors: Santiago Tejedor Calvo and Laura Cervi

Received: 15 July 2022
Accepted: 30 August 2022
Published: 3 September 2022

1. Introduction

In a world that is constantly changing, students need to be engaged and empowered toward sustainability [1]. Education for sustainable development involves educational, and learning activities aimed at developing knowledge, skills, and attitudes to face and solve problems in our society, ensuring the welfare of future generations [2,3]. The educational field is essential to promote sustainable solutions to make students capable of adapting throughout their lives to a changing world, and therefore, nowadays, skills development has received considerable attention [4,5]. Indeed, there is an increasing demand for graduates with creative soft skills [6,7] that will allow them to contribute effectively and positively to the resolution of sustainability problems in their lives, occupations, and communities [8].

Under this sustainable education objective, education is immersed in the process of necessary change, from a focus on teaching to a focus on learning [9], in which innovation has a fundamental role [10]. Innovating in education implies thinking, designing, planning, and assessing projects that solve problems, which are both internal demands and responses to external demands [10].

These innovation processes with new training dynamics and strategies have modified the traditional methodology [11–13] mainly based on teacher instruction and learning through copying, memory, or reproduction [14–16]. Among these new learning methodologies, for example, Guillén-Gámez et al. [17] apply 'cooperative learning' in the development of skills in preservice teachers. Duran and Dökme [18] indicate the significant effects of introducing 'inquiry-based learning' activities to promote critical-thinking skills. Caniglia et al. [19] present and demonstrate how 'experience-based learning' in university-level introductory courses fosters the development of skills in sustainability. Seitamaa-Hakkarainen and Hakkarainen [20] highlight the growing interest in 'learning by making' experiences, and cultivating new manners of thinking and acting. Dag and Durdu [21] implement 'project-based learning' with preservice teachers, who report improved problem-solving and collaboration skills. In these active methodologies, the students become the center of the educational process [22], allowing them to be the protagonist of their own learning and to develop their skill-learning [23]. Nevertheless, conveying this skill-based learning to students in practice is a complex challenge [11,24]. As soft skills are considered transversal matters, courses specifically focused on their development are not often found [25,26].

One of the knowledge areas that positively influence the development of these skills and on which this article focuses is the design field and Design Thinking (DT) in its broadest sense [27–31]. DT consists of the formulation and resolution of complex problems through a creative human-centered process [27,28], being suitable for challenges characterized by a high level of uncertainty, such as most sustainability-related problems [32]. Thus, DT provides a framework (i.e., an innovation approach) for sustainability-oriented innovation (i.e., an innovation outcome) [33]. This sustainable innovation implies the creation of new (or improved) products, services, processes, or practices that aim at environmental or social benefits [33]. Different methodologies are collected under DT [34–36], which habitually consist of three main stages: inspiration, ideation, and implementation [34]. There are many design methods or tools to support the development of the DT stages [37]. The efficiency, affordability, and adaptability of these tools, as well as the highly visual and universal language used, have allowed the DT to be actively applied in different fields outside design [28,38], such as education [39,40].

1.1. Design Thinking (DT) in Education to Develop Soft Skills

The application of DT in the educational environment is becoming increasingly popular. This process provides open-mindedness in students [28,41], a balance between convergent and divergent thinking [42,43], and the development of soft skills [29–31] such as collaboration, problem-solving, or innovation [40,44], which according to Brundiers et al. [8] are key skills in sustainable education. These benefits have made the application of DT in education more and more popular at all levels, from the early years to the university [45–52].

In this sense, research advocates for the concept of training educators as designers [53–55]. Indeed, Mishra and Koehler [56] developed their recognized approach to technological pedagogical content knowledge supported by the concept of educators as designers [57]. The importance of DT is justified because, in their teaching work, the teachers not only transmit knowledge to students but also adopt roles as coaches, resource providers, and designers of their classes, instructional materials, learning experiences, or teaching methodologies [58,59]. Thus, the teacher is responsible for innovating and building 'ways' [10], working with content, tools, and ideas to design experiences for students [56]. Moreover, their teaching work is essential for training students on how to create and live in a sustainable world [60–62]. Teachers should be encouraged to develop skills to understand and internalize the relationship between their teaching work and society's problems [17].

Therefore, the preservice teachers need to be prepared and trained with 'critical thinking, problem-solving, collaboration, and networking skills' [63]; and precisely, DT implies a team learning process, which facilitates constructivist learning, offers a high-level vision, and fosters the 21-st century skills [45,64,65]. Thus, there is interest in training preservice teachers in DT because it may aid in future teaching work to address complex and varied challenges at a local level, such as lesson and curriculum development, student motivation, school climate, relationships, and countless others [57], and at a global level to promote the sustainable development of future students in these soft skills [17].

Nevertheless, despite the global interest in training preservice teachers in DT, at a practical level, the programs and curriculums do generally not include this type of training [66–68]. This is due to barriers of widely varied natures that do training in DT and managing DT projects with large groups of students challenging [52,57]. The DT itself is a multifaceted, messy, and complex process [69,70] that promotes the divergent and the indefinite in a converged and defined environment, placing the educator in an uncertain position [71]. As shifting this thinking or approach is not straightforward, sustainable solutions are needed to facilitate the integration naturally of DT in preservice teacher training.

1.2. Design Project Management Challenge in Remote Learning

A critical challenge for applying DT for sustainable education is related to the difficulty of managing design projects with large groups of students, as well as the long-term (subject duration) planning of such projects. First, for teachers, in this case, those responsible for the training preservice teachers, who must manage large groups of students with a high level of organization, planning, monitoring, and feedback. Second, for the preservice teachers, who act as students who apply the team learning process, acquiring the teamwork skill necessary for learning and personal growth and essential in their future professional work [72,73].

There are many interaction requirements between teachers and students to consider. First, the teacher-teacher interaction must be collaborative [74]. Teachers should desirably come from different work environments or disciplines; they must 'cross their own islands of knowledge' to establish common ground and shared understanding [25]. Likewise, the teacher-student interaction must ensure a shared understanding. The teacher should actively involve the students and establish an atmosphere that avoids division between teacher and students, making that 'the students relax and get involved in the activities in an uninhibited manner' [52]. Therefore, the teacher must foster interest and participation, allowing mistakes, and welcoming opinions, curiosities, questions, and answers [75,76]. Finally, the student-student interaction must be appropriate to achieve teamwork, considering that they can come, like teachers, from different disciplines. Students must learn to work as a cohesive team through smooth communication, structured collaboration [77], and adequate management of different situations that may arise among team members, such as the 'hitchhikers and couch potatoes on teams' (brief definition) [78].

Additionally, these interactions are influenced by remote situations, such as the unforeseen COVID-19 pandemic. In just a few days, abruptly, teachers from different disciplines had to work together towards the new scenario of remote learning [79]. The remote learning concept is understood as the opportunity to provide sustainable education to students without being physically in the same place as the teacher through technology [80]. Remote learning implies that students and teachers remain connected but changing the teacher-student interaction from physical to virtual and making students work as a team through remote meetings. This increased the workload for teachers, who were under great pressure to redesign subjects and infrastructures [79]; however, remote learning is a necessity in times of lockdowns [81], preventing students from experiencing setbacks during school closures [82]. In this regard, COVID-19 has implied the opportunity to adopt remote learning, making the education system immersed in a substantial change toward new teaching and learning models [81,83,84] more student-centered [32]. In addition, according to

Foo et al. [85], new teaching and learning models should not be limited to crisis situations; it is necessary to learn about them to ensure sustainable education and face future and uncertain challenges.

1.3. Project Management Opportunities

To mitigate the difficulty of managing this type of project, the adaptation and incorporation in the education of workflow management methods such as Kanban are of special interest [86,87] and commonly used in software development [88]. The Japanese word 'kanban' means 'visual board'; specifically, the Kanban board is a tool to map and visualize the project workflow. The board is divided into columns to represent a different stage of the workflow, usually: 'Requested,' 'In progress,' and 'Done' [89]. The tasks of the project are visually represented in cards, which progress through these columns according to the progression of the work [90]. Thus, the Kanban board is a project management tool that allows all participants to see the process in a highly visual manner and follow the progress of the project from start to finish, supporting teamwork. Kanban implementation can be either physical (e.g., blackboard, wall, paper, sticky notes, etc.) or virtual via software support [90], essential in scenarios such as COVID-19.

Precisely, the Information and Communication Technologies (ICT) aimed to create and share ideas and content [91] are an opportunity and have a fundamental role in sustainable society [92]. If ICT had already changed our lives [93], the COVID-19 pandemic has boosted them in education [94], making the ed-tech startup sector grow exponentially [95]. ICT favor the development of 21st-century skills [96], is considered key to innovation [97] and must work closely together with DT [98].

As Stolaki and Economides [99] claim, 'to have a sustainable, innovative society, new technologies, education, and creativity training have to be linked and integrated into effective educational and training systems'. Thus, ICT serves as a lever for sustainable education, empowering students to promote their digital skills as future citizens [100].

According to Gómez [101], ICT is considered cognitive tools, i.e., unintelligent instruments that rely on the learner to generate knowledge, placing the responsibility on the learner and not on the computer. Thus, according to Jonassen [102], cognitive tools must support the collaborative construction of knowledge. This implies learning with technology, using technology as a learning tool rather than as an instructional resource [103].

In this context of shifting educational trajectories, in order to efficiently use ICT in remote learning, according to the Mishra and Koehler approach [56], the teacher should consider the knowledge of the: specific contents of the subject, pedagogical strategies for its teaching, and use of ICT [97]. Thus, it is essential for preservice teachers to acquire technological literacy. Technological literacy involves acquiring transformative and expansive skills for a sustainable society from cultural, economic, environmental, and social perspectives. Thus, digital teaching skills serve to build digital citizenship, being closely linked to sustainability [104]. Nevertheless, sometimes the preservice teachers do not develop multiple technology skills, despite the relevance and interest of using them effectively in their classrooms [105–107].

1.4. Software to Manage Projects in Education

Most educational institutions have at their disposal learning management systems platforms such as Moodle, Blackboard, or Canvas [108,109]. In addition, there has been an increase in the educational use of more specific software for managing the work of groups of students during the implementation of projects. For example, Havazík and Pavlíčková [110] applied the Jira software (8.13 version, Atlassian, Sidney, Australia) to students of Computer Science to develop a project to create a computer game. Collaguazo et al. [111] used the Asana software (9.24.0 version, Asana Inc., San Francisco, CA, USA) with students of Telematics Engineering to develop IoT and Cloud Mobile Applications. Gatwood et al. [112] assessed student pharmacists' acceptance and used a cloud-based (Evernote Business) productivity platform. Rysavy and Michalak [113] used Notion software (2.16 version, Notion

Labs Inc., San Francisco, CA, USA) to manage the academic library members during the COVID-19 pandemic. Zhu and Ryzhkov [114] applied the KanbanFlow software (2.0 version, Codekick, Gothenburg, Sweden) to manage a project of a specialized program for bachelors. Likewise, Phillips et al. [115] implemented Slack software (4.25.0 version, Slack Technologies, San Francisco, CA, USA) to create an online community in undergraduate dermatology medical education.

In this line, the implementation of social media sites in education, such as Twitter, blogs, Facebook, or YouTube, has the potential to enhance the teaching and learning of design projects. As Withell et al. [116] or Caruso [117] demonstrate, social media sites can offer the opportunity to investigate users' experiences, reflect and write freely, record and review the process, as well as share or collaborate. All of these opportunities are essential for design projects, which involve investigating, empathizing with the user, collecting information 'on the fly' [116], and especially collaborating and actively participating during the process [117]. About these examples for project management and social media tools, it is observed how, in general, these software solutions are not initially developed for the educational environment. Thus, this type of software needs to consider educational premises to adapt to pedagogical needs [118]. The remote teaching-learning process should not consist of uploading the existing material or digitizing the processes by doing the same as before [119], whereas a digital transformation is required, redesigning processes and involving people [120]. Indeed, in their study, Tejedor et al. [97] show how the students reported the lack of adaptation of the materials in the COVID-19 crisis, assuring that they were exactly the same as in the face-to-face stage. Therefore, a sustainable society requires adopting this digital transformation which implies deep changes and adaptations in emerging educational technologies, innovations, and research [97,121].

Considering all the previous subsections, it can be deduced that there is a global interest in training preservice teachers in DT since it improves the quality of education for future generations toward a sustainable society; assuming that sustainability is not anticipated as a definite result but rather as a global direction that considers long time periods [33]. However, managing DT projects in remote situations such as COVID-19 is a challenge. ICT, understood as useful cognitive tools, can favor the management of this type of project, fostering the use of technology as a learning tool.

Thus, in this study, a multidisciplinary team of specialists (design, technology, and education) worked together to consider educational premises and pedagogical needs to develop a new use of an online board called DT-based board. This board aims to support preservice teachers and the teachers responsible for their training in the implementation and management of remote design projects, empowering preservice teachers to face and solve problems in their future teaching work in a changing world towards a sustainable education. The board is based on the DT process and is embodied in guidance documents and templates, structured on cards according to the Kanban method. The research question is: what is the perception of the usefulness of the DT-based board for sustainable education during its application with preservice teachers?

To answer this research question, this DT-based board was applied with university-level preservice teachers to accomplish team projects to design instructional materials for preschool classrooms. During the application, the perception of the usefulness of the board as supporting the project was assessed through mixed methods. As a result of the learning, generalizable knowledge was established in the form of guidelines for designing and using these types of boards. Therefore, this article provides (1) the foundations of a new DT-based board, (2) replicable experimentation about the perceived usefulness of the board, and (3) guidelines to aid educators and researchers in integrating DT training for sustainable education.

2. Materials and Methods

2.1. Research Context and Sample

Two iterations were conducted for the DT-based board assessment, where a total of 125 preservice teachers aged 19–21 years participated: 56 during the first iteration (course 1); and 69 in the second (course 2). According to the statement terminology of Tong et al. [122], the sampling method was purposive, which involves selecting participants who are expected to provide relevant data pertinent to the research question. Participants were enrolled in the 'Instructional Materials and Resources' subject of the Education degree of the Faculty of Education of the University of (details removed for peer review). This subject is taught in the 2nd year and is compulsory for all preservice teachers. The subject aims to study instructional materials and how to create them; the project of the subject consists of the creation of instructional materials according to real needs from a classroom of local schools (preschool stage) assigned to the preservice teachers. The preservice teachers knew educational practices, as well as the types and classifications of instructional resources, but were novices in designing and creating instructional materials. They were recruited via an explanation during the first class session; all preservice teachers enrolled in the subject voluntarily accepted to take part in the experiment. Then, the preservice teachers were divided into groups of 3 to 4 members to develop the project, which according to Oakley et al. [78], is the optimal number of members. Thus, 15 teams were formed during the first iteration and 18 teams during the second.

2.2. Research Model and Procedure

Applying the DT approach to students without design knowledge and educational technology literacy involves a challenging and critical context; it demands adaptation, management abilities, and a high level of x-disciplinarity. To further define the x-disciplinarity term, note that it is assigned to the set of possibilities of collaborative work: multi-, cross-, inter-, trans- [123]. Thus, an x-disciplinary workgroup was formed by three lecturers specialists in the design, technology, and projects management disciplines; and two lecturers specialists in the didactic field, particularly in the pedagogical bases and the preservice teachers' training curriculum. They worked together, moving away from their own islands of knowledge to create a shared and optimal solution [25]. Of the team members, the two specialist lecturers in didactics and one of the specialist lecturers in design were the teachers of the subject.

The x-disciplinary team worked together to develop the solution based on guidance documents and templates that make the preservice teachers follow the DT process to design their instructional material. Then, the team decided to use a Kanban board with the aim of making it easier for preservice teachers to visualize and follow the workflow of the DT process. The board was digitally supported because of the need for remote learning and the importance of training them in ICT as useful cognitive tools. Likewise, the use of digital platforms also means reducing the use of paper and developing durable materials and resources, promoting sustainability in education.

For this purpose, the team looked for a tool that allows the creation of boards according to the Kanban method, online team collaboration, private use, uploading files, and copying boards. Thus, the Trello software (2.1.3 version, Atlassian, Sidney, Australia) was chosen for meeting the mentioned features, not requiring payments, download, subscription, and the visual and intuitive interface that makes it straightforward to learn. In fact, according to Dean [124], Trello is the 'best project management software tool for getting started,' which is essential considering that preservice teachers are not familiar with technology and project management. Specifically, a Trello board allows the creation of movable columns to add editable cards that incorporate features or attributes such as description, identification tag, date setting, member assignment, chat, checklists, or attachments.

Thus, Trello was used as a shared workspace for preservice teachers to accomplish their projects cooperatively and remotely. Then, the structure and plan were defined, and the first prototype of the DT-based board was implemented. For this, the x-disciplinary team agreed on two main objectives: to aid preservice teachers in managing and structuring the teamwork to design instructional materials guided by the DT process. On the other hand, to aid teachers in managing and monitoring large groups of students in remote design projects. Finally, the prototype was evaluated in two iterations, as mentioned. By improving the prototypes used in the assessments, the final version of the DT-based board, presented in Section 3.1, was developed.

The DT-based board application and assessment lasted one semester (16 weeks) in each of the two iterations. The aim of the subject project for the preservice teachers was to design innovative instructional materials for use and implementation in a real classroom. For this, each team (15 in the first iteration and 18 in the second) was assigned to a local classroom (preschool stage) and their own DT-based board. During each iteration, the teams carried out the following phases based on the DT model 'Double Diamond' [24], shown in Figure 1. The 'Double Diamond' is a synthesized model of DT: the first diamond implies exploring an issue deeply (divergent thinking) and then focusing on a challenge (convergent thinking), and the second diamond involves providing different answers to the challenge (divergent thinking) and then defining the solution (convergent thinking). Thus, this model achieves a balance between convergent and divergent thinking, both of which are essential to developing creative soft skills [29,41,42] in preservice teachers.

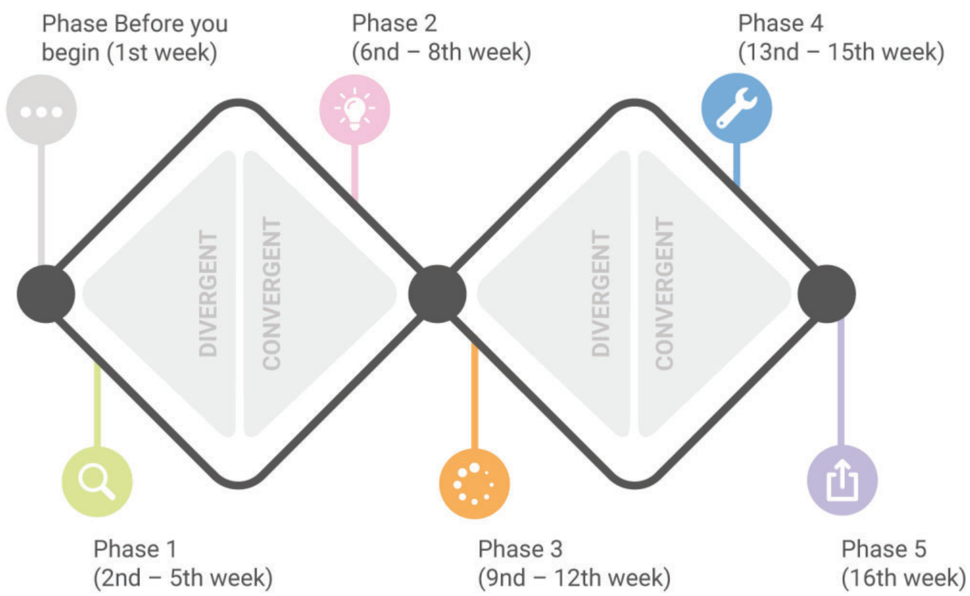


Figure 1. Phases representation based on the double diamond model.

- Phase Before you begin: At the beginning of the project, two workshops with introductory presentations about DT and Trello software were conducted.
- Phase 1: The preservice teachers analyzed the assigned center to detect needs (field research). Thus, using the DT-based board material provided, the preservice teachers accomplished a semi-structured interview with the assigned teacher and conducted context observation in the classroom of the preschool stage assigned. Additionally, they conducted theoretical research related to the main identified need.
- Phase 2: The preservice teachers synthesized the more relevant verbatim quotations of the interview on sticky notes and defined fictitious students' archetypes using the 'Personas' method to empathize with their students and consider their attributes. Likewise, they conducted a group ideation session to address the main identified need, using the 'Brainstorming' method.
- Phase 3: The preservice teachers converted the initial ideas into concepts of instructional materials. For this purpose, they used the '5 whys' technique. They reflected on the following topics (1) what is the main function, (2) what is the most related curricular area, (3) what is the content, (4) what is the didactic objectives, and (5) what

skills it works on. Additionally, they defined formal details of the materials, such as dimensions, materials, shapes, or useful features. They were encouraged to use reused materials (e.g., pallets, packaging, carton, etc.). Finally, through a 'Storyboard' method, the preservice teachers sketched the planned activity to apply their instructional materials in the classroom.

- Phase 4: The preservice teachers built their instructional materials prototypes for the class implementation with reused and low-cost materials. Then, they reflected on the results and proposed solutions or improvements for the activity with their instructional materials. Note that the COVID-19 pandemic implied that, in the first iteration, the preservice teachers did not conduct the assessment; however, the instructional material developed was sent to the preschool stage teacher, who provided feedback.
- Phase 5: At the end of the project, through the presentation phase, the preservice teachers created structured presentations that included the instructional materials created, their application in the class, and the results or feedback obtained.

2.3. Instruments and Data Analysis

The Xassess general framework was used to evaluate the application of the DT-based board in the described environment in both iterations [125]. Xassess is an evaluation methodology that merges qualitative and quantitative approaches, centered on multidisciplinary teams. In this manner, the x-disciplinary team conducted a multi-instrumental assessment with different techniques to obtain information about the perceptions (Table 1). The assessment was conducted in accordance with relevant ethical guidelines [126], providing a verbal and written explanation of the study. Before starting with the survey, students had to agree to a declaration, which informed them about the purpose of the study and assured them of the confidentiality and privacy of the information they provided.

Table 1. Instruments and data analysis to assess the Design Thinking (DT)-based board.

Instruments	Data Analysis
Survey (Quantitative and qualitative)	
Individual surveys were conducted with the preservice teachers using questionnaires with closed and open questions in the Google Forms platform. The purpose was to collect scores and feedback about the usefulness perception of the board as supporting the project by the preservice teachers. The survey included questions about certain relevant concepts, such as the material used (phases, guide documents, etc.), design of instructional materials (project aim), interaction with other students (teamwork), organization of work during the COVID-19 situation, or their future teaching work.	The resulting data were exported to MS Excel. The closed questions were examined using descriptive statistics and visual graphics. These graphics were made with the Python (3.8 version, Python Software Foundation, Wilmington, DE, USA) language. The opened questions were manually coded and grouped according to the thematic analysis approach [127]. Then, the groups of answers were read several times separately by each of the evaluators. In a joint session, they discussed their reflections and justified their suggestions with verbatim quotations to avoid inserting their judgments or beliefs without data from the research.
Observation, field notes, and periodic internal discussion (Qualitative)	
An observation process was also conducted to analyse the behaviour of the preservice teachers'. During the observation, the teachers of the subject collected field notes and accomplished six focus groups in each iteration, distributed during the assessment, 12 in total. In these focus groups, the entire x-disciplinary group attended. The focus groups were online and lasted one hour each.	The field notes were discussed and analysed, and one of the group members created records of the meetings to collect the key concepts shared. Firstly, these annotations complemented the assessment of the usefulness perception of the DT-based board conducted with the survey (see Xassess terminology about complementation). Secondly, to discover the key features and contributions of the DT-based board for teachers collected in the discussion section. Thirdly, to collect deep knowledge and insights on how to design and use this type of board exposed in the guidelines of the discussion section.

Table 1. *Cont.*

Instruments	Data Analysis
Project platform: Trello (Quantitative and qualitative)	
Finally, Trello was used as a source of information for the assessment. On this platform, the preservice teachers scored their usefulness perception of each card at the end of the task. Additionally, the preservice teachers progressively uploaded their work and interacted with the teachers in a loop of doubts and feedback that was recorded for its consultation.	These scores were transcribed to MS Excel, analysed using descriptive statistics, and plotted in Section 3.2. In addition, all data collected on the project platform (Trello) supported the assessment resulting from the other techniques, complementing the results of Section 3 and the guidelines included in the discussion section.

3. Results

3.1. DT-Based Board Features

The following describes the board provided to each preservice teacher team after the two iterations described above. On this board, the students could make modifications to the development of their project.

As shown in Figure 2, each DT-based board has an identifying title and the team members at the top. The board is configured, according to the Kanban board, in 3 columns or lists: 'To do', 'Doing,' and 'Done'. The subject teachers included in the first column 'To do' all the material divided into cards corresponding to the tasks to follow the DT process. In this manner, while the preservice teachers' team was working on one of the tasks, they moved the card to the 'Doing' column. At the end of the task, the team attached the requested files and moved the card to the 'Done' column. Thus, both teachers and preservice teachers had visible the progress and workflows.

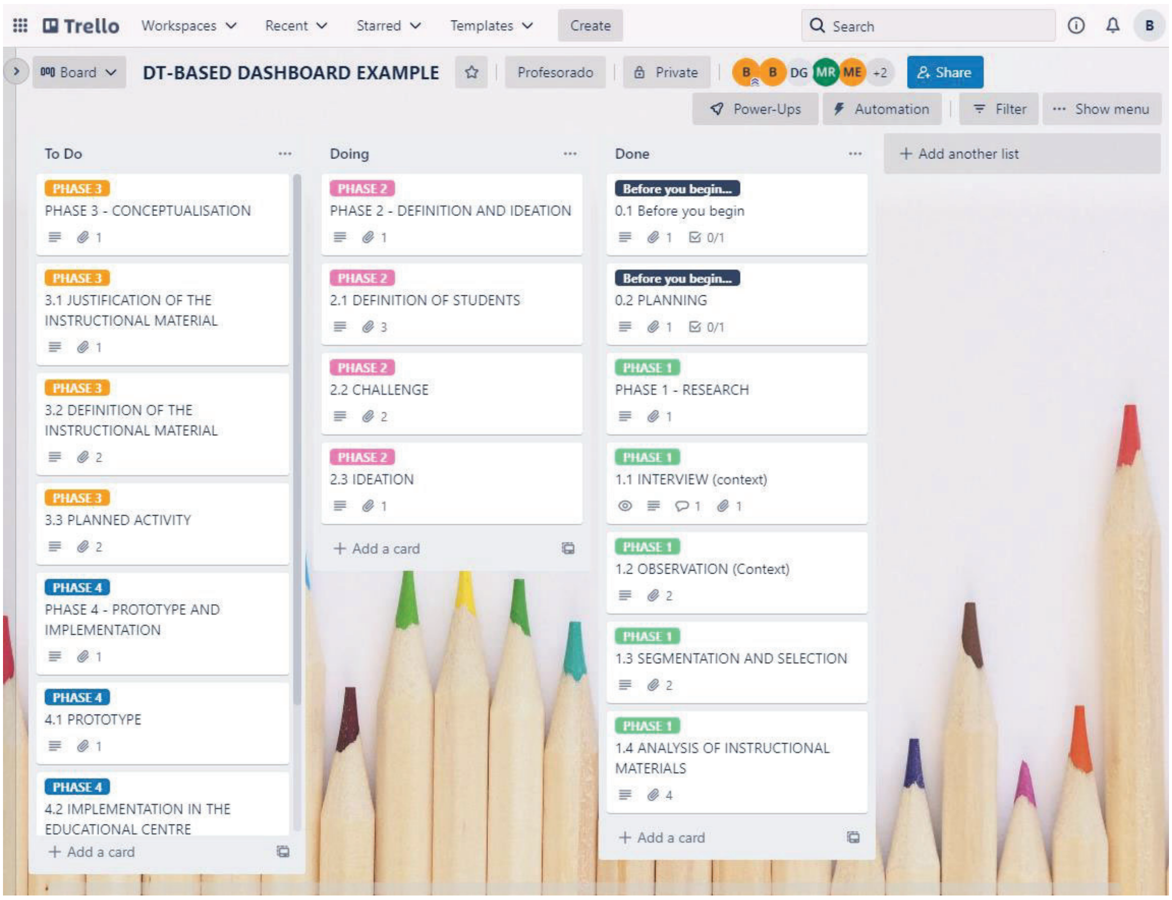
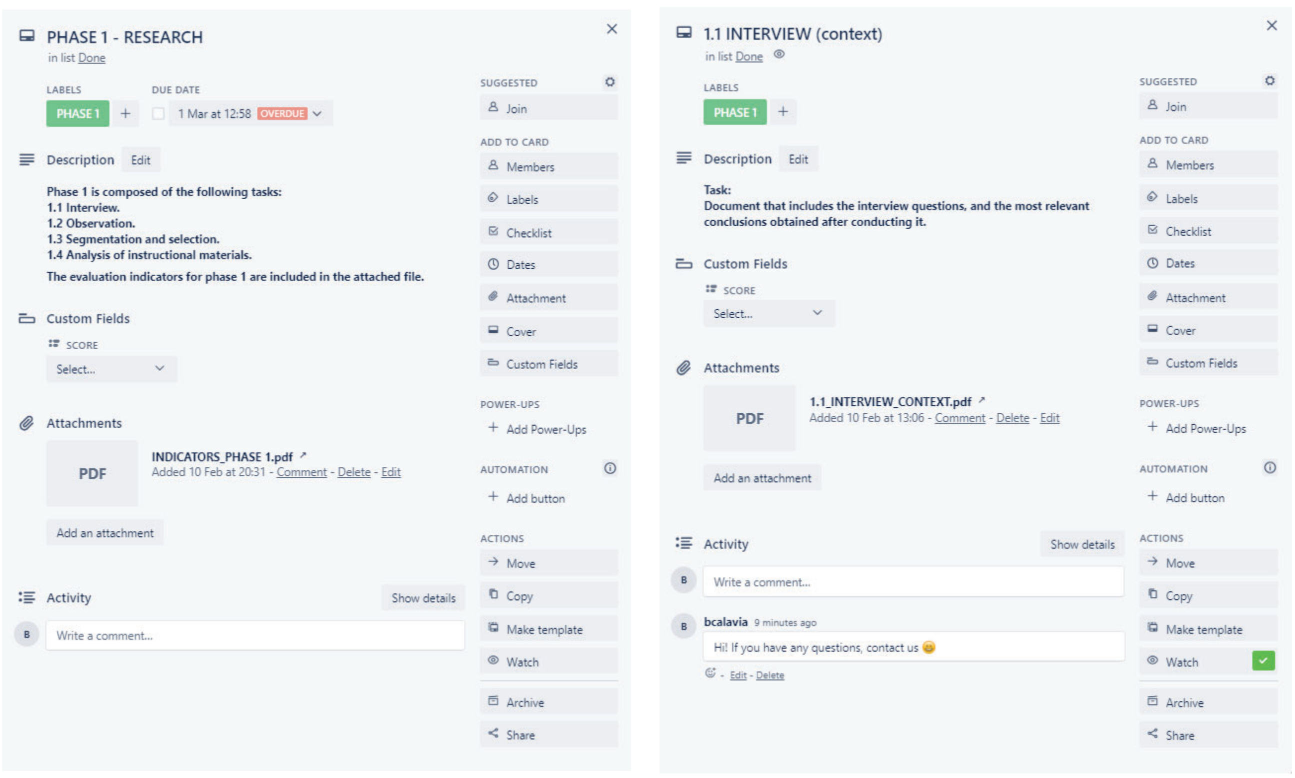


Figure 2. DT-based board example.

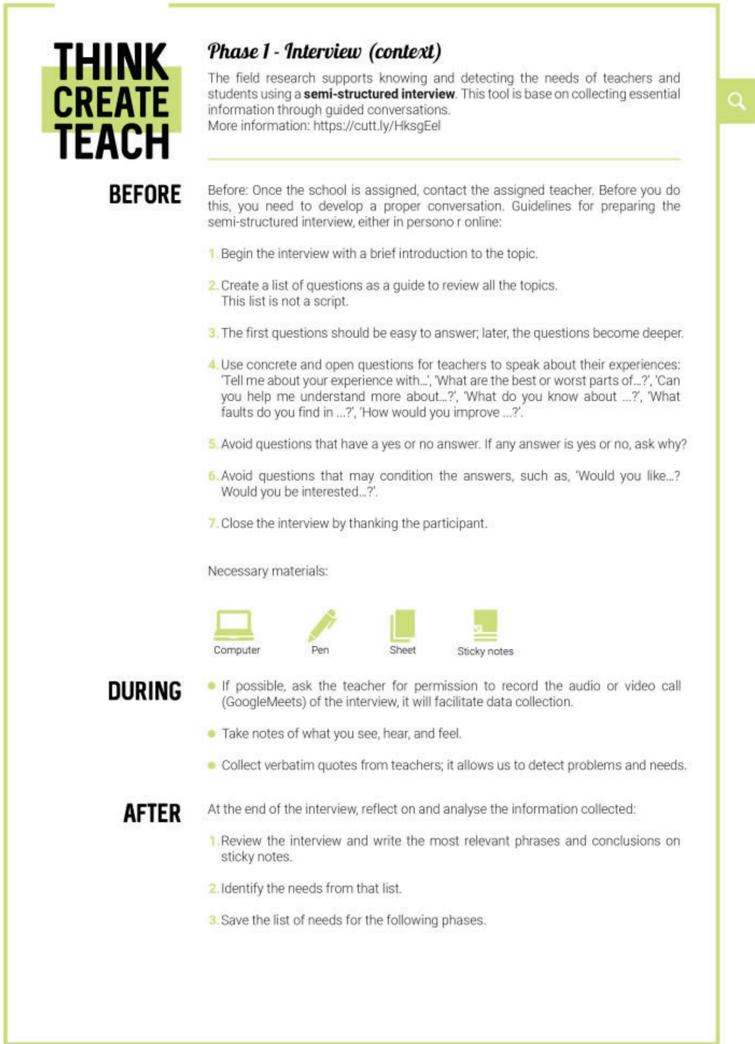
All the cards included in the panel have an identification code composed of three attributes. First, a tag to identify the phase: grey for the 'Before you begin' phase, which includes the introductory cards, green for 'Phase 1', which contains the research cards, pink for 'Phase 2', which incorporates the definition and ideation cards, orange for 'Phase 3', which includes the conceptualization cards, blue for 'Phase 4', which incorporates the prototype and evaluation cards, and purple for 'Phase 5', which contains the presentation cards. Second, a concise title to briefly describe the card. Finally, before the title, a number according to their chronological order. There are two types of cards:

- Six general cards (Figure 3a) aimed to present and explain the objective of each phase and contextualize (before you begin, research, definition and ideation, conceptualization, prototype and implementation, and presentation). These cards include the three attributes mentioned (tag, title, and number), (1) a checklist of the tasks to be completed during the phase, and (2) an advisable date to finish the phase.
- Sixteen specific cards (Figure 3b) aimed to guide the preservice teachers in the DT process, providing techniques, tips, and tasks adapted to the field in question. These cards include—in addition to the three attributes mentioned (tag, title, and number)—(1) a description of the task to be performed; (2) a chat called activity for board members (preservice teachers and teachers of the subject) to talk, ask questions, or leave notes, automatically notifying all board members; (3) an attached guide document to aid the preservice teachers during the specific task execution (Figure 4). Likewise, the preservice teachers can add certain information to each card to facilitate the management and planning of teamwork, such as their start and deadline dates, calendar notes, or member assignments.



(a) (b)

Figure 3. (**a**) General card example (**b**) Specific card example.


THINK
CREATE
TEACH

Phase 1 - Interview (context)

The field research supports knowing and detecting the needs of teachers and students using a **semi-structured interview**. This tool is base on collecting essential information through guided conversations.
More information: https://cutt.ly/HksgEel

BEFORE

Before: Once the school is assigned, contact the assigned teacher. Before you do this, you need to develop a proper conversation. Guidelines for preparing the semi-structured interview, either in persono r online:

1. Begin the interview with a brief introduction to the topic.
2. Create a list of questions as a guide to review all the topics. This list is not a script.
3. The first questions should be easy to answer; later, the questions become deeper.
4. Use concrete and open questions for teachers to speak about their experiences: 'Tell me about your experience with...', 'What are the best or worst parts of...?', 'Can you help me understand more about...?', 'What do you know about ...?', 'What faults do you find in ...?', 'How would you improve ...?'.
5. Avoid questions that have a yes or no answer. If any answer is yes or no, ask why?
6. Avoid questions that may condition the answers, such as, 'Would you like...? Would you be interested...?'.
7. Close the interview by thanking the participant.

Necessary materials:

Computer Pen Sheet Sticky notes

DURING

- If possible, ask the teacher for permission to record the audio or video call (GoogleMeets) of the interview, it will facilitate data collection.
- Take notes of what you see, hear, and feel.
- Collect verbatim quotes from teachers; it allows us to detect problems and needs.

AFTER

At the end of the interview, reflect on and analyse the information collected:

1. Review the interview and write the most relevant phrases and conclusions on sticky notes.
2. Identify the needs from that list.
3. Save the list of needs for the following phases.

Figure 4. Guide document example.

3.2. Usefulness Perception of the DT-Based Board for Preservice Teachers

The following sections include the quantitative and qualitative results of the assessment of the first and second iterations regarding the perception of preservice teachers about the usefulness of the DT-based board.

3.2.1. Usefulness Perception of Each Card for Design the Instructional Materials

Figure 5 shows the mean scores and standard deviations of each card reported by the preservice teachers in Trello after its implementation. In general, the scores are high, and the average score of all cards is 5.8 $\pm$ 1.2 in the first iteration and 6.6 $\pm$ 0.8 (Likert scale from 0–7) in the second iteration.

The cards with the highest scores in both iterations are the 0.3 card, on which preservice teachers asserted 'how important it is to know plan since good learning is based on good planning'; 1.1 'the interview (...) was very enriching and is key to know the context and to start the project'; 2.3 'we used very dynamic and innovative methods that allowed us to think about the appropriate material for the students'; 4.1 'it is to turn all our work into reality'; 5.2 'new design and communication strategies and tools for structured presentations'. In general, the high scores for both iterations are related to the fact that students perceive that 'the guidance documents have allowed us to learn different tools and new methods to create materials in practice' from a 'dynamic, innovative, and novel' point of view.

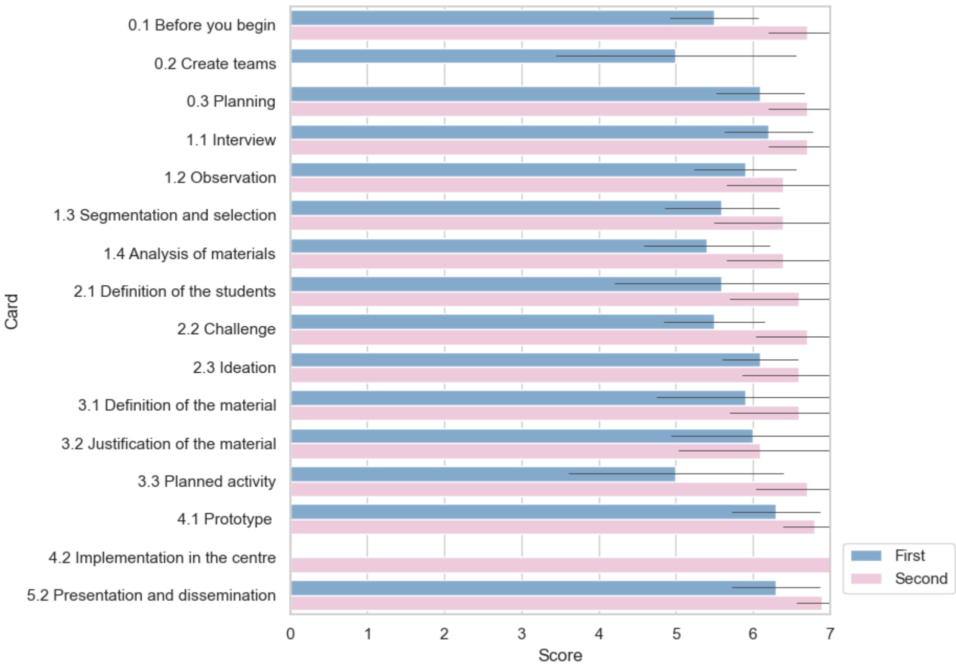


Figure 5. Card scores reported by preservice teachers (mean and standard deviation) in the first and second iterations. Scores range from 0 (minimum valuation) to 7 (maximum valuation).

During the first iteration, the 0.2 card was the worst scored, and as preservice teachers assured, 'it was less useful because I already knew my colleagues'; therefore, in the second iteration, this task was removed. Additionally, other guide documents obtained low scores in the first iteration (0.1; 2.2; 3.3), while they are among the most valued in the second iteration, which evidences the improvements implemented by the x-disciplinary team.

In the second iteration, the 4.2 card was scored with the maximum score by all teams, which coincides with the qualitative perspective '(...) carrying our material and being in the classroom has been incredible'. Note that this card was not scored in the first iteration because the lockdown (COVID-19) prevented preservice teachers from applying their instructional material in the classroom.

3.2.2. Usefulness Perception of the DT-Based Board for the Design of the Instructional Materials

Figure 6 shows the distribution of the perceptions of preservice teachers regarding three main items. In this subsection, we delve into the first item (Figure 6a) related to the question of 'How useful has the DT-based board been to design the instructional material?' whose mean evaluation is 5.2 ± 1.1 in the first iteration and 5.9 ± 1.1 (Likert Scale from 0–7) in the second. As explained in the discussion section, the scores are generally high, and an improvement can be appreciated in the second iteration.

The variety of answers on the contributions of the DT-based board to the design of instructional material (Figure 6a) can be classified into five ideas. (1) The board is useful for planning and organization, 'a structure of the complete process to plan and have everything under control'. (2) It is essential to consider the process, 'learn a process for designing materials, from research to application, reflecting on many aspects which I would not initially have considered'. (3) The board aids with the mental structure, 'It helps to organize ideas that often you do not know how to put together'. (4) The board highlights the ability to act as a designer, 'to learn to design my materials actively and not theoretically'. (5) It provides an enriching experience, 'Thank you for this wonderful experience, it has been one of the projects that I have enjoyed the most, I would do it again'.

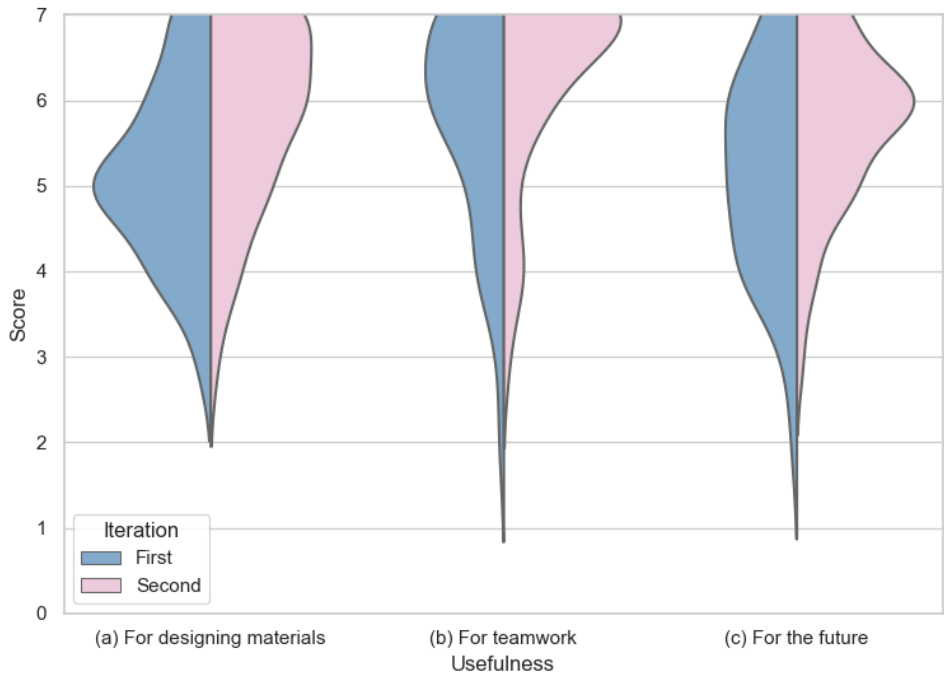


Figure 6. Usefulness perception of the DT-based board for (**a**) designing materials; (**b**) teamwork; (**c**) the future. Scores range from 0 (minimum valuation) to 7 (maximum valuation).

3.2.3. Usefulness Perception of the DT-Based Board for Teamwork

Regarding the question 'Do you consider that the DT-based board has aided teamwork?', as shown in Figure 6b, the mean of the preservice teachers' answers is 5.8 ± 1.2 in the first iteration and 6.3 ± 1.1 in the second (Likert Scale from 0–7). As shown in the violin distribution, the second iteration values are more concentrated than the first iteration, which are more dispersed. In this sense, several students mentioned this improvement during the survey with phrases such as 'it allows me to learn to work cooperatively with a real educational center and with my mates', 'this board has helped us to organize and facilitate teamwork'; 'it provides you new manners of working as a team'.

3.2.4. Usefulness Perception of the DT-Based Board for the Future

Regarding whether 'Would you like to use this DT-based board or any of its phases again in your future teaching work?' the mean of the preservice teachers' responses is 5.2 ± 1.2 in the first iteration and 5.8 ± 1.0 in the second (Likert Scale from 0–7) (Figure 6c). When justifying their answers, the lowest scores refer to 'too many phases to complete'. In contrast, the highest scores report that 'it is essential for our future to have a base with this type of training'.

3.2.5. Usefulness Perception of the DT-Based Board, Although It Is a Laborious Work

Figure 7a refers to the fact that 97.8% of preservice teachers in the first iteration and 100% in the second said that although this method is laborious, it is worth it. It aligns with the reported ideas of the preservice teachers: 'the results and experience achieved worth the effort'; 'understanding the process for my team was not easy; however, I consider it a beneficial manner to get a good result'.

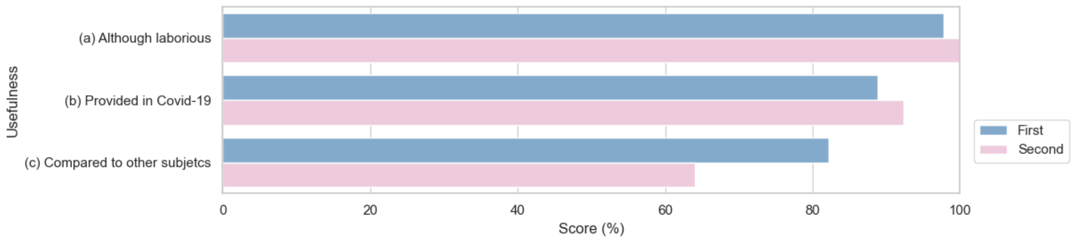


Figure 7. Usefulness perception of DT-based board (**a**) although laborious; (**b**) provided in COVID-19; (**c**) compared to other subjects.

3.2.6. Usefulness Perception of the DT-Based Board in COVID-19 Situation

Concerning the COVID-19 situation, Figure 7b shows the aid provided by the DT-based board to develop the project. In the first iteration, 88.8% affirmed that TCT helped them develop the work in the COVID-19 situation, and 92.3% in the second iteration.

Figure 7c concerns the difference 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. In the second iteration, 64.1% claimed to have noticed an improvement.

Many preservice teachers related this improvement in the COVID-19 situation for four reasons. (1) The continuous work, 'to be in permanent activity, working little by little'. (2) The structure of the DT-based board, 'in other projects, a single document contains everything, while the board is all explained in related sections'. (3) Remote teamwork, 'it was designed for remote use (...) we could do the work through meetings, and we all knew where we were'. (4) The feedback provided, 'the teachers have monitored everything through Trello, and we could contact them directly'.

4. Discussion

This study describes the development of the DT-based board to improve the implementation and management of remote design projects, empowering preservice teachers to face and solve problems in their future teaching work towards a sustainable education. The board was assessed in two consecutive iterations regarding the perceptions of the preservice teachers (students) and the teachers responsible for their training. From this experimentation, generalizable knowledge was established in the form of guidelines to aid researchers and educators in designing and using these types of boards.

The assessment demonstrated the board's usefulness to support and conduct DT projects remotely, specifically for the design of instructional materials. This achievement is materialized for several reasons. First, specialists from different disciplines designed and developed the DT-based board considering educational premises from the beginning: the specific preservice teachers' needs and knowledge, the curriculum features, the time available, and the project's scope. Second, and probably as a result of the first, preservice teachers showed positive attitudes toward the DT-based board materials; the average score on all cards was high (5.8 ± 1.2 in the first and 6.6 ± 0.8 in the second iteration on a scale from 0–7, see Figure 5).

Likewise, the board, structured according to the Kanban method, allowed the preservice teachers 'to have an overview of the project at a glance' (teachers of the subject) with an agile learning curve. Some learning management solutions can be challenging to use (for both teachers and students) because they are overwhelming, have much functionality that is not always known or applied, and require training and excessive time. However, the DT-based board embedded on Trello is user-friendly, flexible, and allows organizing projects visually; it is like a board full of post-its. It is beneficial for remote learning because it simulates the tangible murals or boards they are familiar with, allowing the student to participate actively through ICT [128], considering ICT as useful cognitive tools [101]. Furthermore, the use of ICT contributes to the development of digital teaching skills, which according to Colás-Bravo et al. [104], are essential for sustainable digital citizenship.

Thus, the use of the DT-based board was especially useful in the COVID-19 situation, as indicated by the preservice teachers (88.8% in the first and 92.3% in the second iteration). Solutions provided in crisis situations, such as COVID-19, make education sustainable at present and facilitate facing future and uncertain challenges in the long term [81]. In this line, the preservice teachers perceived an improvement in comparison to other subject projects developed in the same COVID-19 situation. It should be noted that in the second iteration, preservice teachers indicated less difference from other subjects; this is understandable because many teachers evolve towards ed-tech [95].

Following the perception of the usefulness of the DT-based board for the design and development of instructional materials, the preservice teachers indicated high scores (5.2 ± 1.1 in the first and 5.9 ± 1.1 in the second iteration on a scale from 0–7, see Figure 6a). The board allowed preservice teachers to not only visualize, but also follow 'a structured, cohesive, reflective, flexible, and justified design process' (teachers of the subject); in line with Kleon [129], it provided them with the opportunity to understand the importance of thinking about the process, not only about the result. To help the preservice teachers to assimilate this concept, we focused on evaluation and continuous feedback during the process, rewarding the willingness to explore, discover and innovate [130]. This DT process allowed the preservice teachers to develop human-centered and well-founded instructional materials 'they do not make a material because they have seen it on Pinterest, but there is a reasoning and a justification behind' (teachers of the subject). It is related to Carroll [131], Howard, et al. [27], and Mosely et al. [28] that ensure that design is focused on human-centered problem formulation and problem-solving. Likewise, this boosts competence learning, fosters research, facilitates 'learning-by-doing,' and provides new valuable tools and methods for their future and sustainable teaching work. Thus, numerous preservice teachers considered this training useful for their future teaching work (5.2 ± 1.2 in the first and 5.8 ± 1.0 in the second iteration on a scale from 0–7, see Figure 6c); the preservice teachers who reported the lowest scores justified it with the numerous phases to complete. However, as indicated by 97.8% in the first iteration and 100% in the second: the method is laborious, but it is worth it.

Regarding the project management, we highlight teamwork since, according to the results, the DT-based board facilitated participation and interaction in the preservice teacher teams during the project (student-student): 'it allowed a better climate among the members (...) everyone was involved' (teachers of the subject). Also, the board was used as a communication tool between teacher-students 'Boards allowed us to be connected and monitor each team's progress, avoiding behind-scheduled groups' (teachers of the subject). Thus, this board improved and facilitated the labor of the teachers responsible for the preservice teacher's training and management of remote design projects, adapting communication to each group according to their project stage [132,133].

As a general comment, the results during the second iteration were more favorable than in the first iteration. This effect is understandable for two reasons. First, because in the second iteration, the preservice teachers had the opportunity to apply their instructional materials in the classroom, whereas in the first iteration, they were not due to the lockdown (COVID-19). This may influence the improvement of the preservice teachers' perceptions (second iteration) about the board's usefulness to support their work because, according to their comments, testing their materials in the classroom enriched the experience. This reflection aligns with the results of González-Calvo et al. [134] research on the feelings of teachers in initial training during COVID-19. Second, because the DT-based board was designed through an iterative process, which implies that after each evaluation, improvements were applied. Figure 5 shows how some of the guidance documents that obtained low scores in the first iteration were among the most highly scored in the second iteration. This result demonstrates how the x-disciplinary team improved the DT-based board, focusing on those perceived as less useful. Thus, this board is not closed but is in continuous change.

This iterative design process conducted cooperatively between different disciplines (x-disciplinary team), together with the assessment process conducted from the beginning of the project, permitted extracting deep and structured conclusions, giving rise to key contributions at a methodological level. These findings are presented as guidelines for designing and using this type of board, which are shown below, organized in three blocks. These guidelines may be useful for educators and researchers to develop practical and sustainable solutions to promote DT training. According to Guillén-Gámez et al. [17], it is necessary to implement strategies to foster education for sustainable development.

4.1. Project Organisation and Connection

The entire workspace must be carefully organized to manage student projects with software like Trello. At the teacher level, it is interesting to start creating a workspace with the subject's name (course name), which collects all the boards corresponding to the student teams of the same subject. In this manner, if the teacher uses the Trello software (2.1.3 version, Atlassian, Sidney, Australia) in several subjects, they have a workspace for each of them (Figure 8a). For example, for the detailed assessment, in each iteration, we created a workspace called 'Instructional Materials and Resources' (name of the subject), in which there were a total of 15 boards in the first iteration and 18 boards in the second iteration (corresponding to the preservice teacher teams). According to Oakley et al. [78] and Blanco et al. [11], the number of students per team should not exceed five to avoid division in the same group, and between three and four is an ideal number.

Figure 8. Trello organisation and content (**a**) workspace; (**b**) board; (**c**) general card; (**d**) specific card; guide document (**e**).

Each of these boards should have a name that identifies the group of students; this helps the teachers identify the groups and the students consolidate as a team. To organize the board, Trello allows creating columns to add cards; in our case, we have tried several combinations. In the beginning, we created a first column named 'material', and according to the agile Kanban method [135], a second column called 'to do,' a third column called 'doing,' and a fourth column called 'done'. The aim was that the teacher would move the cards from the 'material' column to 'to do' as the project progressed; however, this created extra work for the teachers because they had to add new cards in the 'to do' column. Therefore, we decided to place the material directly in 'to do,' with the aim that students develop their autonomy and can manage the tasks in progress, those they are working on, and those they have completed, without the teacher intervening in this process (Figure 8b).

To transform the subject material into software like Trello is not about uploading a document for students to read. Still, it is necessary to create a process in which the material and Trello are connected and complement each other. Likewise, it should be noted that, in line with Dorst and Cross [136], DT is an iterative and non-linear process, posing flexibility as a fundamental consideration. The material must be connected and divided into manageable, flexible, and easily movable cards. Thus, the flexibility of the material developed should make it adaptable to the characteristics of each project; because each work is different, and not all student teams do the same thing during a project. For example, in our case, there were groups of students that analyzed the needs detected, while in other cases, the need was clear; or there were teams that analyzed existing instructional materials during the research and others after the ideation when the idea was more defined.

It is useful to have two types of cards. On the one hand, general cards (Figure 8c) aimed to introduce the phase, the tasks to be carried out, and an advisable date to finish the phase. On the other hand, specific cards (Figure 8d) aimed to guide the students in the DT process, providing methods, tips, and tasks that led them to create instructional materials. Recommended attributes to include in these cards:

- To start creating these cards, it is helpful to establish tags to help students visualize the stages of the project; as in our case, we created a tag with a name and color assigned to each phase. In addition, we recommend adding a 'before you begin' tag for the introduction cards, which are designed to explain the project, the material, and the use of Trello (because not all students attend the explanation class).
- A concise title preceded by a number according to the numerical chronology. Although, as mentioned above, the process must be flexible because not all groups follow the same one, we consider that this enumeration helps students to situate themselves and follow the process less chaotically.
- A task description to include the task to be accomplished. In the first iteration, we added only one statement. Still, we found (during the second iteration) that it was more effective and more straightforward for the students to include what they should submit, for example, 'Task: Document that includes the interview questions, and the most relevant conclusions obtained after conducting it'.
- A chat in which students can comment on doubts, and teachers can give feedback adapted to the team's specific situation. It is recommended that teachers add an initial comment on the card to create a climate of trust, e.g., 'Hi! If you have any questions, contact us'.
- Attached documents that guide the student during the project. These documents should be connected and complemented with the cards to form a single material, i.e., the students have to understand the board and the materials as one. For this purpose, at a visual level, these guide documents should use the same name, number, color, and similar aesthetic. For example, in Figure 8e, pink is used, corresponding to the phase 2 tag used on the board, and the same name and title as on the board card. In addition, at a structural level, it is important that these guide documents keep their organization simple, clear, and connected to the board. Thus, after the two iterations were conducted, we concluded that a 'before', 'during', and 'after' structure is optimal for developing such projects, and the best manner to provide information is through tips. When the students start reading, the 'before' section introduces them to where they are and provides tips for preparing for the task. The 'during' section gives them recommendations and indications on how to conduct it. Finally, the 'after' section explains how to process and analyze the information collected. This last step (after) must be directly connected to the task described in the card to facilitate the process.

4.2. Project Development

At the beginning of the project, it is important to place in context those students who are not trained in DT, project management, or software of this type, considering them as novices in these fields. During this introduction, it is advisable to show visual examples of design (e.g., the origin of things and some design cases), the process of DT, the sustainable education concept, as well as the connection of this to their training, their subject project, and their future teaching work. Likewise, for the software explanation, the boards for each team must be previously created, and each team member should be previously invited to join. In this manner, all students will follow the training session step by step. During the session, it is advisable to start from the general visualization to the more concrete specifications: panel structure, columns, cards, card contents, and card movements.

It is essential to highlight that the provided board is a flexible tool on which each team can, for example: create new columns and cards, go back between phases, change the order of the cards, set specific dates on the cards for planning, as well as establish which members are going to carry out each task. In short, to transmit that the board is not closed but can be adapted to their team's project.

While students develop the project, they follow the DT process and internalize it. However, it should be noted that the DT is a multifaceted, messy, and complex process [34,69,70]. Therefore, students must understand that at the beginning, it is normal for them to feel uncertainty and to perceive the process as chaotic. Still, then, during the project, they come to understand the process, see the meaning, and achieve more reflective outcomes [34]. For the development of the project, we adapted the following DT methods: 'semi-structured interview' and 'observation notes' to detect and understand the needs and characteristics of the teacher, students, and classroom; 'Personas' to define students; 'Brainstorming' to ideate; '5 whys' to justify the instructional material; 'Storyboard' to define the implementation of the instructional material in the classroom; as well as 'Prototype' to apply and assess the instructional material in the class.

However, these methodologies are suitable for teamwork, and although the panel is collaborative, it does not allow creating online group sessions. Thus, the teacher should establish programmed sessions using applications such as Google Meet. Even more enriching is the possibility for each team to have its own 'virtual canvas' to work on through virtual templates and sticky notes. Figure 9 details an example created from a Google Drive presentation. In this example, the created template is placed as a fixed background, and a stack of rectangles is added, simulating sticky notes. In this manner, team members discuss through Meets and collaboratively share the information; changes occur in real-time and are visible to all members. This working method is beneficial for conducting remote workshops guided by the teacher, such as the Phase 2 'Personas' (Figure 9).

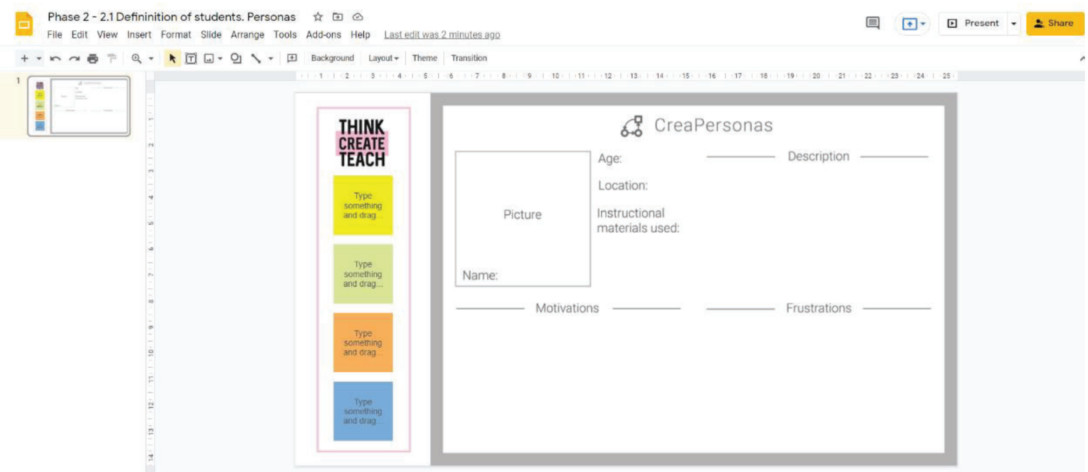


Figure 9. Example of a virtual canvas for teamwork.

In addition, it is essential to highlight some remarks that, in our case, smoothed the interactions between teacher-student during the development of the project:

- To establish a comfortable climate for students to ask questions and participate in the project in an uninhibited manner [52], allowing for mistakes and avoiding fear of failure [75,76].
- To monitor boards and provide feedback by answering questions and making general follow-up comments. To facilitate this task is recommended to have sets of comments and add a 'waiting' column on the board for students to add the cards with questions.
- According to Han et al. [137], it is essential to make students understand that the board is not to spy on them but to support them, as well as not provide too much feedback because it makes them constantly seek approval, and they must control their dependency on support.

4.3. Project Evaluation

Project management with such a board provides data to evaluate both the students (assessment of the process and the final result) and the teacher's work. Firstly, the teacher actively monitors the students during the project's development. The teacher can visualize the work of each group, check the submission dates, know which groups are working daily and which at the end, detect the changes of each board in real-time, visualize the doubts of the groups at the moment, and give feedback adapted to each group, know the tasks done correctly, incorrectly, or not done, as well as the outcomes of the project. In addition, this information is collected on the board to aid teachers to review it again for the project assessment. It is recommended to assess each project individually to evaluate the entire process (the issues raised, the decisions taken, or the context of each team). It implies that both teachers and students value the importance of process, continuous assessment, and constructivist learning, rather than just the result, in line with Kleon [129].

Secondly, these data allow the teacher to visualize and self-evaluate their own subject material by different indicators. For example, teachers can see which tasks have been the most challenging and whether their feedback had a positive effect. Likewise, it is advisable to add a 'score' tab on each card (Figure 8d), allowing the team to score the card at the end of the task (in our case, a scale of 0–7); so that the teacher can then analyze which cards have been most and least useful. Finally, it is interesting to add an 'evaluation' card at the end of the project; in our case, we use this card to add a Google Form.

4.4. Sustainability Position

Finally, in order to weave slightly further the sustainable position, it is interesting to reverse the arguments provided in the theoretical framework of this article. Doing this mental process, the bind between this study to the sustainability concept can be visualized as a big chain. The first element of the chain is the DT-based board and their associated guidelines; they contribute to applying DT effectively in remote situations such as COVID-19, facing relevant challenges such as managing large groups of preservice teachers. Achieving this effective application of DT leads to the second element of the chain: enabling preservice teachers to foster DT skills such as problem-solving [29–31,44]. This training based on problem-solving will lead preservice teachers to the third and most general element in our chain: contributing to sustainable education for future generations, which is essential in a changing world and levers a sustainable society [8].

4.5. Limitations of Study

This study has some limitations and further work to address. First, the scope of this study is limited to preservice teachers from a particular university, so it would be interesting to extend the applications to other environments to have a more extensive study. Second, the proposed guidelines aim to describe the experience and findings of a practical example of DT application to consider its potential in practice. However, generalization is not the focus of this paper, and such guidelines are neither unique nor strict. Third, understanding and internalizing DT is not a simple task because the design is multifaceted, messy, and complex. It requires continuous training over time; thus, using the DT-based board is not a unique solution but a step towards introducing these concepts in preservice teacher training.

5. Conclusions

This paper contributes with a DT-based board to improve the implementation and management of remote design projects for large groups of students of preservice teachers, empowering them towards a sustainable education. The board results from the collaborative work of specialists from different disciplines (design, technology, and education), who considered educational premises to adapt it to pedagogical needs and address the digital transformation. Thus, this board is built on a replicable and flexible process in which the developed material is connected and complemented with existing software (Trello), being understood as a single entity. This approach provides a visual and flexible organization, allowing the development and management of design projects to be accessible, even without great knowledge of design, project management, and technology. This board was assessed and improved through two iterations with preservice teachers who used the DT-based board to conduct design projects to develop instructional materials for preschool stage classrooms.

In conclusion, the DT-based board is considered useful according to the preservice teachers' perceptions because it allows them to overview the project from the beginning, follow the DT process remotely, understand the importance of the process, design human-centered instructional materials, and develop soft skills for sustainability. Specifically, the board enhances teamwork skills during the project because it smooths interactions and serves as a communication tool between student-student and teacher-student. Likewise, the board facilitates the project management of preservice teachers, guided, supervised, and adaptively led by the teachers responsible for their training. It is especially useful for remote learning in situations such as the COVID-19 pandemic. In addition, this study provides useful guidelines for designing and using these boards to aid educators and researchers in integrating DT training and developing practical and sustainable solutions. These guidelines allow the DT-based board to be easily replicated and incorporated into an existing course without significant changes to the curriculum.

As a general conclusion, internalizing the DT process through a board to manage projects and using technology with an agile learning curve aids preservice teachers in facing complex and varied challenges in their future teaching work. This approach contributes to the natural integration of DT and ICT in preservice teachers' education, improving the quality of education for future generations toward a sustainable society.

Author Contributions: Conceptualization, M.B.C., T.B., R.C. and B.D.; Data curation, M.B.C. and B.D.; Formal analysis, M.B.C. and R.C.; Funding acquisition, M.B.C., T.B. and R.C.; Investigation, M.B.C.; Methodology, M.B.C., T.B., R.C., and B.D.; Project administration, T.B. and R.C.; Resources, T.B., R.C., and B.D.; Supervision, T.B. and R.C.; Visualization, M.B.C.; Writing—original draft, M.B.C.; Writing—review & editing, T.B., R.C. and B.D. All authors have read and agreed to the published version of the manuscript.

Funding: This work was partially supported by the Government of Aragon, under Grant BOA20180615027 under Grant T27_17R, and by the Spanish MINECO under Grant PTQ2018-010045.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Before starting with the survey, students had to agree to a declaration, which informed them about the purpose of the full study and assured them of the confidentiality and the privacy of the information provided.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to thank the preservice teachers who participated in this study. This project would not have been possible without their participation and their feedback. Finally, we would like to thank the Government of Aragon and the Spanish MINECO for the financial support.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Lynch, M.; Andersson, G.; Johansen, F.R. Merging Systems Thinking with Entrepreneurship: Shifting Students' Mindsets Towards Crafting a More Sustainable Future. *Sustainability* **2021**, *13*, 4946. [CrossRef]
2. Nousheen, A.; Zai, S.A.Y.; Waseem, M.; Khan, S.A. Education for Sustainable Development (ESD): Effects of Sustainability Education on Pre-Service Teachers' Attitude Towards Sustainable Development (SD). *J. Clean. Prod.* **2020**, *250*, 119537. [CrossRef]
3. Tejedor, G.; Sánchez-Carracedo, F.; Segalàs, J. Education for Sustainable Development in Higher Education-Introduction to a Special Issue. *Sustainability* **2022**, *14*, 10530. [CrossRef]
4. Geisinger, K.F. 21st Century Skills: What are they and how do we Assess them? *Appl. Meas. Educ.* **2016**, *29*, 245–249. [CrossRef]
5. Mishra, P.; Mehta, R. What we Educators Get Wrong about 21st-Century Learning: Results of a Survey. *J. Digit. Learn. Teach. Educ.* **2017**, *33*, 6–19. [CrossRef]
6. Moore, T.; Morton, J. The Myth of Job Readiness? Written Communication, Employability, and the 'skills Gap'in Higher Education. *Stud. High. Educ.* **2017**, *42*, 591–609. [CrossRef]
7. Clarke, M. Rethinking Graduate Employability: The Role of Capital, Individual Attributes and Context. *Stud. High. Educ.* **2018**, *43*, 1923–1937. [CrossRef]
8. Brundiers, K.; Barth, M.; Cebrián, G.; Cohen, M.; Diaz, L.; Doucette-Remington, S.; Dripps, W.; Habron, G.; Harré, N.; Jarchow, M. Key Competencies in Sustainability in Higher Education—toward an Agreed-upon Reference Framework. *Sustain. Sci.* **2021**, *16*, 13–29. [CrossRef]
9. Tejada Fernández, J.; Navío Gámez, A.; Ruiz Bueno, C. La Didáctica De Un Entorno Virtual Interuniversitario: Experiemtación De ECTS Apoyados En TIC. *Pixel-Bit. Rev. Medios Y Educ.* **2007**, *30*, 95–118.
10. Pérez Tornero, J.M.; Tejedor Calvo, S. *Ideas Para Aprender a Aprender: Manual De Innovación Educativa y Tecnología*; Editorial UOC: Barcelona, Spain, 2016.
11. Blanco, T.; López-Forniés, I.; Zarazaga-Soria, F.J. Deconstructing the Tower of Babel: A Design Method to Improve Empathy and Teamwork Competences of Informatics Students. *Int. J. Technol. Des. Educ.* **2017**, *27*, 307–328. [CrossRef]
12. Hoogveld, A.W.; Paas, F.; Jochems, W.M. Training Higher Education Teachers for Instructional Design of Competency-Based Education: Product-Oriented Versus Process-Oriented Worked Examples. *Teach. Teach. Educ.* **2005**, *21*, 287–297. [CrossRef]
13. Martínez, M.C.; Manzano, M.J.R.; Lema, L.E.C.; Andrade, L.C.V. Formación Por Competencias: Reto De La Educación Superior. *Rev. Cienc. Soc.* **2019**, *25*, 94–101. [CrossRef]
14. Lee, M.; Erdogan, I. The Effect of Science–technology–society Teaching on Students' Attitudes Toward Science and Certain Aspects of Creativity. *Int. J. Sci. Educ.* **2007**, *29*, 1315–1327. [CrossRef]
15. McMullan, M.J. How using Technology Enhanced Learning could Help Modernise Traditional Large Group Teaching Or Lecturing. *Int. J. Innov. Res. Med. Sci. (IJIRMS) (Online)* **2016**, *1*, 2245–8737. [CrossRef]
16. Nguyen, K.A.; DeMonbrun, R.M.; Borrego, M.J.; Prince, M.J.; Husman, J.; Finelli, C.J.; Shekhar, P.; Henderson, C.; Waters, C. The Variation of Nontraditional Teaching Methods Across 17 Undergraduate Engineering Classrooms. In Proceedings of the 2017 ASEE Annual Conference & Exposition, Columbus, OH, USA, 24 June 2017.
17. Guillén-Gámez, F.D.; Higueras-Rodríguez, L.; Medina-García, M. Developing a Regression Model of Cooperative Learning Methodology in Pre-Service Teacher Education: A Sustainable Path for Transition to Teaching Profession. *Sustainability* **2020**, *12*, 2215. [CrossRef]
18. Duran, M.; Dökme, I. The Effect of the Inquiry-Based Learning Approach on Student's Critical-Thinking Skills. *Eurasia J. Math. Sci. Technol. Educ.* **2016**, *12*, 2887–2908. [CrossRef]
19. Caniglia, G.; John, B.; Kohler, M.; Bellina, L.; Wiek, A.; Rojas, C.; Laubichler, M.D.; Lang, D. An Experience-Based Learning Framework: Activities for the Initial Development of Sustainability Competencies. *Int. J. Sustain. High. Educ.* **2016**, *17*, 827–852. [CrossRef]
20. Seitamaa-Hakkarainen, P.; Hakkarainen, K. *Learning by Making. The SAGE Encyclopedia of Out-Of-School Learning*; Sage Publications: Thousand Oaks, CA, USA, 2017.
21. Dag, F.; Durdu, L. Pre-Service Teachers' Experiences and Views on Project-Based Learning Processes. *Int. Educ. Stud.* **2017**, *10*, 18–39. [CrossRef]
22. Moya, E.C. Using Active Methodologies: The StudentśView. *Procedia-Soc. Behav. Sci.* **2017**, *237*, 672–677. [CrossRef]
23. Starkey, L. Three Dimensions of Student-Centred Education: A Framework for Policy and Practice. *Crit. Stud. Educ.* **2019**, *60*, 375–390. [CrossRef]
24. Wilhelm, W.J.; Logan, J.; Smith, S.M.; Szul, L.F. *Meeting the Demand: Teaching "Soft" Skills*; Delta Pi Epsilon Publishers: Little Rock, Arkansas, 2002.

25. Blanco, T.; Casas, R.; Manchado-Pérez, E.; Asensio, Á.; López-Pérez, J.M. From the Islands of Knowledge to a Shared Understanding: Interdisciplinarity and Technology Literacy for Innovation in Smart Electronic Product Design. *Int. J. Technol. Des. Educ.* **2017**, *27*, 329–362. [CrossRef]
26. Fernandes, J.M.; van Hattum-Janssen, N.; Ribeiro, A.N.; Fonte, V.; Santos, L.P.; Sousa, P. An Integrated Approach to Develop Professional and Technical Skills for Informatics Engineering Students. *Eur. J. Eng. Educ.* **2012**, *37*, 167–177. [CrossRef]
27. Howard, T.J.; Culley, S.J.; Dekoninck, E. Describing the Creative Design Process by the Integration of Engineering Design and Cognitive Psychology Literature. *Des. Stud.* **2008**, *29*, 160–180. [CrossRef]
28. Mosely, G.; Wright, N.; Wrigley, C. Facilitating Design Thinking: A Comparison of Design Expertise. *Think. Skills Creat.* **2018**, *27*, 177–189. [CrossRef]
29. Luka, I. Design Thinking in Pedagogy. *J. Educ. Cult. Soc.* **2014**, *5*, 63–74. [CrossRef]
30. Naghshbandi, S. Exploring the Impact of Experiencing Design Thinking on Teachers' Conceptualizations and Practices. *TechTrends* **2020**, *64*, 868–877. [CrossRef]
31. Wright, N.; Wrigley, C. Broadening Design-Led Education Horizons: Conceptual Insights and Future Research Directions. *Int. J. Technol. Des. Educ.* **2017**, *29*, 1–23. [CrossRef]
32. Victorino, G.; Bandeira, R.; Painho, M.; Henriques, R.; Coelho, P.S. Rethinking the Campus Experience in a Post-COVID World: A Multi-Stakeholder Design Thinking Experiment. *Sustainability* **2022**, *14*, 7655. [CrossRef]
33. Buhl, A.; Schmidt-Keilich, M.; Muster, V.; Blazejewski, S.; Schrader, U.; Harrach, C.; Schäfer, M.; Süßbauer, E. Design Thinking for Sustainability: Why and how Design Thinking can Foster Sustainability-Oriented Innovation Development. *J. Clean. Prod.* **2019**, *231*, 1248–1257. [CrossRef]
34. Brown, T.; Wyatt, J. Design Thinking for Social Innovation. *Dev. Outreach* **2010**, *12*, 29–43. [CrossRef]
35. Design Council. Available online: https://www.designcouncil.org.uk/ (accessed on 7 September 2021).
36. Stanford University Institute of Design. Available online: http://dschool.stanford.edu/our-point-of-view/#design-thinking (accessed on 7 September 2021).
37. Maguire, M. Methods to Support Human-Centred Design. *Int. J. Hum.-Comput. Stud.* **2001**, *55*, 587–634. [CrossRef]
38. Dorst, K. The Nature of Design Thinking. In Proceedings of the 8th Design Thinking Research Symposium, Sydney, Australia, 19 October 2010.
39. Lor, R. Design Thinking in Education: A Critical Review of Literature. In Proceedings of the International Academic Conference on Social Sciences and Management/Asian Conference on Educational and Psychology, Bangkok, Thailand, 24 May 2017.
40. Razzouk, R.; Shute, V. What is Design Thinking and Why is it Important? *Rev. Educ. Res.* **2012**, *82*, 330–348. [CrossRef]
41. Thorsteinsson, G.; Page, T. Teaching Creativity Across the Curriculum through Design Education. Case Studies. *Educ. 21* **2017**, *15*, 13–22. [CrossRef]
42. Gu, X.; Dijksterhuis, A.; Ritter, S.M. Fostering Children's Creative Thinking Skills with the 5-I Training Program. *Think. Skills Creat.* **2019**, *32*, 92–101. [CrossRef]
43. Hadar, L.L.; Tirosh, M. Creative Thinking in Mathematics Curriculum: An Analytic Framework. *Think. Skills Creat.* **2019**, *33*, 100585. [CrossRef]
44. Brown, T. Design Thinking. *Harv. Bus. Rev.* **2008**, *86*, 84.
45. Pande, M.; Bharathi, S.V. Theoretical Foundations of Design thinking–A Constructivism Learning Approach to Design Thinking. *Think. Skills Creat.* **2020**, *36*, 100637. [CrossRef]
46. Coleman, M.C. Design Thinking and the School Library. *Knowl. Quest* **2016**, *44*, 62–68.
47. Grammenos, D.; Antona, M. Future Designers: Introducing Creativity, Design Thinking & Design to Children. *Int. J. Child-Comput. Interact.* **2018**, *16*, 16–24.
48. Carroll, M.; Goldman, S.; Britos, L.; Koh, J.; Royalty, A.; Hornstein, M. Destination, Imagination and the Fires within: Design Thinking in a Middle School Classroom. *Int. J. Art Des. Educ.* **2010**, *29*, 37–53. [CrossRef]
49. Scheer, A.; Noweski, C.; Meinel, C. Transforming Constructivist Learning into Action: Design Thinking in Education. *Des. Technol. Educ. Int. J.* **2012**, *17*, 8–19.
50. McKilligan, S.; Fila, N.; Rover, D.; Mina, M. Design Thinking as a Catalyst for Changing Teaching and Learning Practices in Engineering. In Proceedings of the 2017 IEEE Frontiers in Education Conference, Indianapolis, Indiana, 18 October 2017.
51. Jordan, M.E. Teaching as Designing: Preparing Pre-Service Teachers for Adaptive Teaching. *Theory Into Pract.* **2016**, *55*, 197–206. [CrossRef]
52. Calavia, M.B.; Blanco, T.; Casas, R. Fostering Creativity as a Problem-Solving Competence through Design: Think-Create-Learn, a Tool for Teachers. *Think. Skills Creat.* **2021**, *39*, 100761. [CrossRef]
53. Bennett, S.; Agostinho, S.; Lockyer, L. The Process of Designing for Learning: Understanding University Teachers' Design Work. *Educ. Technol. Res. Dev.* **2017**, *65*, 125–145. [CrossRef]
54. Hernández-Leo, D.; Agostinho, S.; Beardsley, M.; Bennet, S.; Lockyer, L. Helping Teachers to Think about their Design Problem: A Pilot Study to Stimulate Design Thinking. In Proceedings of the 9th International Conference on Education and New Learning Technologies, Barcelona, Spain, 3 July 2017.
55. Kirschner, P.A. Do we Need Teachers as Designers of Technology Enhanced Learning? *Instr. Sci.* **2015**, *43*, 309–322. [CrossRef]
56. Mishra, P.; Koehler, M.J. Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge. *Teach. Coll. Rec.* **2006**, *108*, 1017–1054. [CrossRef]

57. Henriksen, D.; Richardson, C.; Mehta, R. Design Thinking: A Creative Approach to Educational Problems of Practice. *Think. Skills Creat.* **2017**, *26*, 140–153. [CrossRef]
58. McKenney, S.; Kali, Y.; Markauskaite, L.; Voogt, J. Teacher Design Knowledge for Technology Enhanced Learning: An Ecological Framework for Investigating Assets and Needs. *Instr. Sci.* **2015**, *43*, 181–202. [CrossRef]
59. Norton, P.; Hathaway, D. In Search of a Teacher Education Curriculum: Appropriating a Design Lens to Solve Problems of Practice. *Educ. Technol.* **2015**, *55*, 3–14.
60. Sund, L. Facing Global Sustainability Issues: Teachers' Experiences of their Own Practices in Environmental and Sustainability Education. *Environ. Educ. Res.* **2016**, *22*, 788–805. [CrossRef]
61. Ashmann, S.; Franzen, R.L. In what Ways are Teacher Candidates being Prepared to Teach about the Environment? A Case Study from Wisconsin. *Environ. Educ. Res.* **2017**, *23*, 299–323. [CrossRef]
62. Fien, J. Teaching for a Sustainable World: The Environmental and Development Education Project for Teacher Education. *Environ. Educ. Res.* **1995**, *1*, 21–33. [CrossRef]
63. Şendağ, S.; Odabaşı, H.F. Effects of an Online Problem Based Learning Course on Content Knowledge Acquisition and Critical Thinking Skills. *Comput. Educ.* **2009**, *53*, 132–141. [CrossRef]
64. Goldman, S.; Zielezinski, M.B. Teaching with design thinking: Developing new vision and approaches to twenty-first century learning. In *Connecting Science and Engineering Education Practices in Meaningful Ways*; Annetta, L.A., Minogue, J., Eds.; Springer: Cham, Switzerland, 2016; pp. 237–262.
65. Stokholm, M. Problem Based Learning Versus Design Thinking in Team Based Project Work. In Proceedings of the 16th International Conference on Engineering and Product Design Education, Design Education and Human Technology Relations, University of Twente, Enschede, The Netherlands, 4 September 2014.
66. Elwood, K.; Savenye, W.; Jordan, M.E.; Larson, J.; Zapata, C. Design Thinking: A New Construct for Educators. In Proceedings of the Annual Convention of the Association of Educational Communications and Technology, Las Vegas, NV, USA, 17–21 October 2016.
67. Gleason, B.; Cherrez, N.J. Design Thinking Approach to Global Collaboration and Empowered Learning: Virtual Exchange as Innovation in a Teacher Education Course. *TechTrends* **2021**, *65*, 348–358. [CrossRef]
68. Kali, Y.; McKenney, S.; Sagy, O. Teachers as Designers of Technology Enhanced Learning. *Instr. Sci.* **2015**, *43*, 173–179. [CrossRef]
69. Dym, C.L.; Agogino, A.M.; Eris, O.; Frey, D.D.; Leifer, L.J. Engineering Design Thinking, Teaching, and Learning. *J. Eng. Educ.* **2005**, *94*, 103–120. [CrossRef]
70. Teal, R. Developing a (Non-linear) Practice of Design Thinking. *Int. J. Art Des. Educ.* **2010**, *29*, 294–302. [CrossRef]
71. López, O. Enseñar Creatividad: El Espacio Educativo. *Cuad. De La Fac. De Humanid. Y Cienc. Sociales. Univ. Nac. De Jujuy* **2008**, 61–75. Available online: https://www.redalyc.org/pdf/185/18512511006.pdf (accessed on 14 July 2022).
72. De Prada, E.; Mareque, M.; Pino-Juste, M. Teamwork Skills in Higher Education: Is University Training Contributing to their Mastery? *Psicol. Reflexão E Crítica* **2022**, *35*, 1–13. [CrossRef]
73. Riebe, L.; Roepen, D.; Santarelli, B.; Marchioro, G. Teamwork: Effectively Teaching an Employability Skill. *Educ. Train.* **2010**, *52*, 528–539. [CrossRef]
74. Goddard, Y.L.; Goddard, R.D.; Tschannen-Moran, M. A Theoretical and Empirical Investigation of Teacher Collaboration for School Improvement and Student Achievement in Public Elementary Schools. *Teach. Coll. Rec.* **2007**, *109*, 877–896. [CrossRef]
75. Fasko, D. Education and Creativity. *Creat. Res. J.* **2001**, *13*, 317–327. [CrossRef]
76. Feldhusen, J.F.; Treffinger, D.J. *Creative Thinking and Problem Solving in Gifted Education*; Kendall/Hunt Publishing Company: Dubuque, IA, USA, 1985.
77. Lingard, R.; Barkataki, S. Teaching Teamwork in Engineering and Computer Science. In Proceedings of the 2011 Frontiers in Education Conference, Rapid City, SD, USA, 12 October 2011.
78. Oakley, B.; Felder, R.; Brent, R.; Elhajj, I. Coping with Hitchhikers and Couch Potatoes on Teams. *J. Stud. Cent. Learn.* **2004**, *2*, 32–34.
79. Tejedor, S.; Cervi, L.; Tusa, F.; Parola, A. University Teachers Face the Change to Virtual Education Imposed by the Coronavirus. *Soc. E Estado* **2021**, *36*, 915–943. [CrossRef]
80. Baranova, S.; Nīmante, D.; Kalniņa, D.; Oļesika, A. Students' Perspective on Remote on-Line Teaching and Learning at the University of Latvia in the First and Second COVID-19 Period. *Sustainability* **2021**, *13*, 11890. [CrossRef]
81. Ali, W. Online and Remote Learning in Higher Education Institutes: A Necessity in Light of COVID-19 Pandemic. *High. Educ. Stud.* **2020**, *10*, 16–25. [CrossRef]
82. Morgan, H. Best Practices for Implementing Remote Learning during a Pandemic. *Clear. House A J. Educ. Strateg. Issues Ideas* **2020**, *93*, 135–141. [CrossRef]
83. Alam, A. Challenges and Possibilities of Online Education during Covid-19. *Prepints* **2020**, 2020060013. Available online: https://www.preprints.org/manuscript/202006.0013/v1 (accessed on 14 July 2022).
84. Kalantzis, M.; Cope, B. After the COVID-19 Crisis: Why Higher Education may (and perhaps should) Never be the Same. *ACCESS Contemp. Issues Educ.* **2020**, *40*, 51–55. [CrossRef]
85. Foo, C.; Cheung, B.; Chu, K. A Comparative Study regarding Distance Learning and the Conventional Face-to-Face Approach Conducted Problem-Based Learning Tutorial during the COVID-19 Pandemic. *BMC Med. Educ.* **2021**, *21*, 141. [CrossRef]

86. Parsons, D.; Thorn, R.; Inkila, M.; MacCallum, K. Using Trello to Support Agile and Lean Learning with Scrum and Kanban in Teacher Professional Development. In Proceedings of the 2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering, Wollongong, NSW, Australia, 4 December 2018.
87. López-Alcarria, A.; Olivares-Vicente, A.; Poza-Vilches, F. A Systematic Review of the use of Agile Methodologies in Education to Foster Sustainability Competencies. *Sustainability* **2019**, *11*, 2915. [CrossRef]
88. Brechner, E. *Agile Project Management with Kanban*; Pearson Education: London, UK, 2015.
89. Schwaber, K.; Sutherland, J. The Scrum Guide. *Scrum Alliance* **2011**, *21*, 1.
90. Kanbanize. Available online: https://kanbanize.com/kanban-resources/getting-started/what-is-kanban-board (accessed on 7 September 2021).
91. Henriksen, D.; Mishra, P.; Fisser, P. Infusing Creativity and Technology in 21st Century Education: A Systemic View for Change. *Educ. Technol. Soc.* **2016**, *19*, 27–37.
92. Sánchez-Cruzado, C.; Santiago, R.; Sánchez-Compaña, M. Teacher Digital Literacy: The Indisputable Challenge After COVID-19. *Sustainability* **2021**, *13*, 1858. [CrossRef]
93. Bilbao-Osorio, B.; Dutta, S.; Lanvin, B. *The Global Information Technology Report 2013: Growth and Jobs in a Hyperconnected World*; World Economic Forum and INSEAD: Geneva, Switzerland, 2013.
94. Salas-Rueda, R.; Castañeda-Martínez, R.; Eslava-Cervantes, A.; Alvarado-Zamorano, C. Teachers' Perception about MOOCs and ICT during the COVID-19 Pandemic. *Contemp. Educ. Technol.* **2022**, *14*, ep343. [CrossRef]
95. Edtech. Available online: https://www.brighteyevc.com/post/the-european-edtech-funding-report-2022 (accessed on 7 September 2021).
96. Lewin, C.; McNicol, S. Supporting the Development of 21st Century Skills through ICT. In *KEYCIT 2014-Key Competencies in Informatics and ICT*; Brinda, T., Reynolds, N., Romeike, R., Schwill, A., Eds.; Manchester Metropolitan University: Manchester, UK, 2015; pp. 181–198.
97. Tejedor, S.; Cervi, L.; Pérez-Escoda, A.; Tusa, F.; Parola, A. Higher Education Response in the Time of Coronavirus: Perceptions of Teachers and Students, and Open Innovation. *J. Open Innov. Technol. Mark. Complex.* **2021**, *7*, 43. [CrossRef]
98. Goto, S.; Ishida, S.; Gemba, K.; Yaegashi, K. The Interaction between design research and technological research in manufacturing firm. In *Smart Manufacturing Innovation and Transformation: Interconnection and Intelligence*; IGI Global: Hershey, PA, USA, 2014; pp. 226–251.
99. Stolaki, A.; Economides, A.A. The Creativity Challenge Game: An Educational Intervention for Creativity Enhancement with the Integration of Information and Communication Technologies (ICTs). *Comput. Educ.* **2018**, *123*, 195–211. [CrossRef]
100. Carrión-Martínez, J.J.; Luque-de la Rosa, A.; Fernandez-Cerero, J.; Montenegro-Rueda, M. Information and Communications Technologies (ICTs) in Education for Sustainable Development: A Bibliographic Review. *Sustainability* **2020**, *12*, 3288. [CrossRef]
101. Gómez, O.Y.A. Las TIC Como Herramientas Cognitivas. *Rev. Interam. De Investig. Educ. Y Pedagog.* **2018**, *11*, 67–80.
102. Jonassen, D.H. Thinking Technology: Toward a Constructivist Design Model. *Educ. Technol.* **1994**, *34*, 34–37.
103. Jonassen, D.H. *Computers as Mindtools for Schools: Engaging Critical Thinking*; Prentice hall: Hoboken, NJ, USA, 2000.
104. Colás-Bravo, P.; Conde-Jiménez, J.; Reyes-de-Cózar, S. Sustainability and Digital Teaching Competence in Higher Education. *Sustainability* **2021**, *13*, 12354. [CrossRef]
105. Gibson, P.A.; Stringer, K.; Cotten, S.R.; Simoni, Z.; O'neal, L.J.; Howell-Moroney, M. Changing Teachers, Changing Students? The Impact of a Teacher-Focused Intervention on Students' Computer Usage, Attitudes, and Anxiety. *Comput. Educ.* **2014**, *71*, 165–174. [CrossRef]
106. Mourlam, D.J.; Strouse, G.A.; Newland, L.A.; Lin, H. Can they do it? A Comparison of Teacher Candidates' Beliefs and Preschoolers' Actual Skills with Digital Technology and Media. *Comput. Educ.* **2019**, *129*, 82–91. [CrossRef]
107. Saini, C.; Abraham, J. Implementing Facebook-Based Instructional Approach in Pre-Service Teacher Education: An Empirical Investigation. *Comput. Educ.* **2019**, *128*, 243–255. [CrossRef]
108. Carvalho, A.; Areal, N.; Silva, J. Students' Perceptions of Blackboard and Moodle in a Portuguese University. *Br. J. Educ. Technol.* **2011**, *42*, 824–841. [CrossRef]
109. Kraleva, R.; Sabani, M.; Kralev, V. An Analysis of some Learning Management Systems. *Int. J. Adv. Sci. Eng. Inf. Technol.* **2019**, *9*, 1190–1198. [CrossRef]
110. Havazík, O.; Pavlíčková, P. How to Design Agile Game for Education Purposes in JIRA. In Proceedings of the 2020 7th International Conference on Control, Decision and Information Technologies, Prague, Czech Republic, 29 June 2020.
111. Collaguazo, A.; Villavicencio, M.; Abran, A. Education Model for Developing IoT and Cloud Mobile Applications. In Proceedings of the 2020 IEEE World Congress on Services, Beijing, China, 18 October 2020.
112. Gatwood, J.; Hohmeier, K.; Kocak, M.; Chisholm-Burns, M. Acceptance of Productivity Software as a Course Management and Collaboration Tool among Student Pharmacists. *Curr. Pharm. Teach. Learn.* **2021**, *13*, 361–367. [CrossRef]
113. Rysavy, M.D.; Michalak, R. Working from Home: How we Managed our Team Remotely with Technology. *J. Libr. Admin.* **2020**, *60*, 532–542. [CrossRef]
114. Zhu, T.; Ryzhkov, O. Application of Agile Methodology in Planning a Joint Educational Program. In Proceedings of the 2021 IEEE International Conference on Smart Information Systems and Technologies, Nur-Sultan, Kazakhstan, 28 April 2021.
115. Phillips, A.; Edwards, S.; Parmesar, K.; Soltan, M.; Guckian, J. Slack as a Virtual Undergraduate Dermatology Community: A Pilot Study. *Clin. Exp. Dermatol.* **2021**, *46*, 1028–1037. [CrossRef]

116. Withell, A.; Cochrane, T.; Reay, S.; Gaziulusoy, I.; Inder, S. Augmenting the Design Thinking Studio. In Proceedings of the Australian Society for Computers in Learning in Tertiary Education Annual Conference, Wellington, New Zealand, 25–28 November 2012.
117. Caruso, C. The Tools of Engagement: Bridging Design Thinking and Social Media to Enhance and Support Collaborative Learning. Doctoral Dissertation, Carleton University, Ottawa, ON, Canada, 2011.
118. Tuhkala, A.; Kärkkäinen, T. Using Slack for Computer-Mediated Communication to Support Higher Education Students' Peer Interactions during Master's Thesis Seminar. *Educ. Inf. Technol.* **2018**, *23*, 2379–2397. [CrossRef]
119. Jang, S. Exploration of Secondary Students' Creativity by Integrating Web-Based Technology into an Innovative Science Curriculum. *Comput. Educ.* **2009**, *52*, 247–255. [CrossRef]
120. Admiraal, W.; Louws, M.; Lockhorst, D.; Paas, T.; Buynsters, M.; Cviko, A.; Janssen, C.; de Jonge, M.; Nouwens, S.; Post, L. Teachers in School-Based Technology Innovations: A Typology of their Beliefs on Teaching and Technology. *Comput. Educ.* **2017**, *114*, 57–68. [CrossRef]
121. Cerdá Suárez, L.M.; Núñez-Valdés, K.; Quirós y Alpera, S. A Systemic Perspective for Understanding Digital Transformation in Higher Education: Overview and Subregional Context in Latin America as Evidence. *Sustainability* **2021**, *13*, 12956. [CrossRef]
122. Tong, A.; Sainsbury, P.; Craig, J. Consolidated Criteria for Reporting Qualitative Research (COREQ): A 32-Item Checklist for Interviews and Focus Groups. *Int. J. Qual. Health Care* **2007**, *19*, 349–357. [CrossRef]
123. Blanco, T.; Casas, R.; López, J.M. Common Understanding Area (CUA): An X-Disciplinary Design Tool for Technological Innovation. In Proceedings of the 2018 XIII Technologies Applied to Electronics Teaching Conference, La Laguna, Spain, 20 June 2018.
124. Dean, D. Available online: https://www.thebalancesmb.com/best-project-management-software-4175032 (accessed on 7 September 2021).
125. Blanco, T.; Berbegal, A.; Blasco, R.; Casas, R. Xassess: Crossdisciplinary Framework in User-Centred Design of Assistive Products. *J. Eng. Des.* **2016**, *27*, 636–664. [CrossRef]
126. Lodico, M.G.; Spaulding, D.T.; Voegtle, K.H. *Methods in Educational Research: From Theory to Practice*; John Wiley & Sons: Hoboken, NJ, USA, 2010.
127. Patton, M.Q. *Qualitative Research & Evaluation Methods: Integrating Theory and Practice*; Sage publications: Thousand Oaks, CA, USA, 2014.
128. Schmid, R.F.; Bernard, R.M.; Borokhovski, E.; Tamim, R.M.; Abrami, P.C.; Surkes, M.A.; Wade, C.A.; Woods, J. The Effects of Technology use in Postsecondary Education: A Meta-Analysis of Classroom Applications. *Comput. Educ.* **2014**, *72*, 271–291. [CrossRef]
129. Kleon, A. *Aprende a Promocionar Tu Trabajo: 10 Recursos Para Artistas, Diseñadores Y Creativos*; Gustavo Gili: Barcelona, Spain, 2016.
130. Erbas, A.K.; Bas, S. The Contribution of Personality Traits, Motivation, Academic Risk-Taking and Metacognition to the Creative Ability in Mathematics. *Creat. Res. J.* **2015**, *27*, 299–307. [CrossRef]
131. Carroll, M.P. Shoot for the Moon! the Mentors and the Middle Schoolers Explore the Intersection of Design Thinking and STEM. *J. Pre-Coll. Eng. Educ. Res. (J-PEER)* **2014**, *4*, 3. [CrossRef]
132. Noguera, I.; Guerrero-Roldán, A.; Masó, R. Collaborative Agile Learning in Online Environments: Strategies for Improving Team Regulation and Project Management. *Comput. Educ.* **2018**, *116*, 110–129. [CrossRef]
133. Uebe, A.F.; Alves, A.C.; Torres, R.B. Trello as Virtual Learning Environment and Active Learning Organiser for PBL Classes: An Analysis Under Bloom's Taxonomy. In Proceedings of the 11th International Symposium on Project Approaches in Engineering Education and 16th Active Learning in Engineering Education Workshop, Tunis, Tunisia, 10–12 June 2019.
134. González-Calvo, G.; Barba-Martín, R.A.; Bores-García, D.; Gallego-Lema, V. Aprender a Ser Docente Sin Estar En Las Aulas: La Covid-19 Como Amenaza Al Desarrollo Profesional Del Futuro Profesorado. *Int. Multidiscip. J. Soc. Sci.* **2020**, *9*, 152–177. [CrossRef]
135. Ahmad, M.O.; Liukkunen, K.; Markkula, J. Student Perceptions and Attitudes Towards the Software Factory as a Learning Environment. In Proceedings of the 2014 IEEE Global Engineering Education Conference, Istanbul, Turkey, 3 April 2014.
136. Dorst, K.; Cross, N. Creativity in the Design Process: Co-Evolution of Problem-solution. *Des. Stud.* **2001**, *22*, 425–437. [CrossRef]
137. Han, J.; Kim, K.H.; Rhee, W.; Cho, Y.H. Learning Analytics Dashboards for Adaptive Support in Face-to-Face Collaborative Argumentation. *Comput. Educ.* **2021**, *163*, 104041. [CrossRef] [PubMed]

3.6. Estudio 6

Calavia, M. B., Blanco, T., Serrano, A., Biedermann, A., & Casas, R. (2022). Think-Sketch-Create: Improving Creative Expression Through Sketching. In Gerbino, S., Lanzotti, A., Martorelli, M., Mirálbes Buil, R., Rizzi, C., Roucoules, L. (Eds.), *Advances on Mechanics, Design Engineering and Manufacturing IV. JCM 2022. Lecture Notes in Mechanical Engineering* (pp. 1585-1597). Springer, Cham.

https://doi.org/10.1007/978-3-031-15928-2_138

BD: SJR | FI: 0.19 | Q: *Mechanical Engineering* (Q4)

Q: *Automotive Engineering* (Q4)

Q: *Aerospace Engineering* (Q4)

Q: *Fluid Flow and Transfer Processes* (Q4)

Think-Sketch-Create: Improving Creative Expression Through Sketching

M. Belén Calavia[1,2(✉)], Teresa Blanco[2,3], Ana Serrano[1], Anna Biedermann[1], and Roberto Casas[2,4]

[1] Department of Design and Manufacturing Engineering, University of Zaragoza, Zaragoza, Spain
bcalavia@unizar.es
[2] HOWLab - Human OpenWare Research Group, Aragon Institute of Engineering Research (I3A), University of Zaragoza, Zaragoza, Spain
[3] Department of Musical, Plastic and Body Language Expression, University of Zaragoza, Zaragoza, Spain
[4] Department of Electronic Engineering, University of Zaragoza, Zaragoza, Spain

Abstract. Sketching skills are fundamental for engineers, especially in the field of design. However, developing this skill is not straightforward; most first-year students only have technical drawing training and the attempt to achieve hyperrealism finishes usually blocks them. Based on multidisciplinary work, this study presents a teaching intervention: the 'Think-Sketch-Create' (TSC) workshops aimed to help students improve their skills to express their thoughts and ideas through sketching. These workshops consist of two blocks: warm-up and experimentation. The TSC workshops are applied and assessed through qualitative and quantitative methods in a subject with 84 university students. The assessment of the TSC workshops shows its positive integration into the curriculum, its utility to establish a satisfactory climate to avoid blockage without fear of making mistakes, and its ability to broaden knowledge. In short, this paper evidences the interest of training future engineers in sketching and the need to support teachers with new methods that aid them to foster creative expression in their students.

Keywords: Design education · Teaching skills · Sketching · Workshop design · Creativity

1 Introduction

The need for professionals with boundary-crossing skills in different work sectors of today's world requires training students through competency-based learning [1, 2]. Indeed, the concept of 'skill' is understood as the dynamic combination of knowledge, understanding, and abilities that prepare students for their future employment and role in society [3]. Thus, in the engineering context, and especially in the design and Design Thinking (DT) fields, one of the most relevant skills to be developed by the students is the expression of thoughts and ideas with sketches [4–6].

S. Gerbino et al. (Eds.): JCM 2022, LNME, pp. 1585–1597, 2023.
https://doi.org/10.1007/978-3-031-15928-2_138

DT is based on formulating and solving complex problems through an analytical and creative human-centred process [7–12]. This process generally consists of three main phases: inspiration, ideation, and implementation [13]. Sketches have an essential role during specific moments of these DT phases, such as ideation, conceptualisation, and presentation. Sketching allows designers to develop, externalise, record, and communicate the ideas they have in mind and to generate new ones [14]. Therefore, there is a strong relationship between sketching and DT.

Likewise, sketching is related to creativity [15], one of the most important 21st-century thinking skills, understood as the ability to connect learned knowledge to solve problems and create new things [16, 17]. Expression through sketching favours creative problem solving through methods such as Visual Thinking (VT), which provides the analogies needed to develop new structures [18]. Therefore, most creative processes extensively use visual thinking, and thus, sketching is considered a means of stimulating and supporting creative thinking.

However, teaching and developing the ability to express thoughts with sketches is not straightforward. Children draw without caring whether they do it right or wrong; nevertheless, this language and spontaneity are lost when they are instructed. Most academic environments generally consider drawing and creativity a pastime in practice [19]. In this sense, most first-year engineering students have not used drawing as a means of communication for years, and their previous training is primarily technical. Likewise, their drawings' attempt to achieve perfection or hyperrealism leads to a blockage that prevents them from developing this sketching skill. As a result, many students often use only verbal language to communicate their ideas during ideation and 3D modelling and rendering software to conceptualise and present solutions.

This effect is partly because, according to Norp and Van Hoek [20], many times during the training programs, students spend hours creating 'perfect' colour gradients or getting the right lines to produce the most excellent final drawing they can achieve. Nevertheless, this is not aligned with professional practice; it is more helpful for their future to express themselves through sketching quickly and collaboratively, fostering communication between group participants through a common ground for discussion: the sketches.

In engineering training, some studies propose tools for teaching sketching skills. However, there are few interventions focused on reducing the blockage to develop this skill [4]: Worinkeng, Summers, and Joshi [21] proposed a pre-sketching activity to foster concept generation and Booth et al. [4] raised 'freehand sketching' and 'sketch inhibition' modules to reduce inhibition. Meanwhile, in the field of artistic education, activities to teach sketching and address the blockage are more common; these activities seek to use the right side of the brain, enhancing creativity [22]. Thus, practical solutions are needed to help teachers popularise creative expression through sketching in future engineers as a universal language, aligning better the relationship between training and professional practice of design sketching.

To address this situation, in the following sections of this paper, we present a workshop called Think-Create-Sketch (TCS). Section 2 shows the rationale, the application, and the assessment of the TCS workshop. Section 3 collects the results and discussion of the TCS assessment, conducted in a real educational environment with end users (engineering students), by qualitative and quantitative methods. From this experimentation, the TCS's utility, the advantages, difficulties, and limitations derived from its implementation, and the feedback necessary for its improvement are discussed.

2 Materials and Methods

2.1 Workshop Rationale and Definition

A high level of x-disciplinarity is required to design and incorporate a new method in the educational environment. X-disciplinarity is a term assigned to the set of possibilities of collaborative work: multi-, cros-, inter-, trans- [23]. Thus, in this research, a multidisciplinary team comprised of specialists in design, art, architecture, creativity, and technology was created. From the beginning, the five members of the team (manuscript authors) worked together during several sessions, considering the visions and experiences of each discipline. The sessions were focused on modifying the methodology based on hyperrealism or perfect finishes by activities that lead students to experiment and open new doors of discovery. Some verbatims about the team's intention were collected during the sessions: 'Sketching and not rendering', 'We want them to experiment', 'Dynamics to free them from the blockage', 'Foster creativity'.

From the collaboration between disciplines, we propose workshops called 'Think-Sketch-Create' (TSC), which aims to help students improve their skill of expression through sketching, reducing the blockage. These workshops consist of 3-h sessions structured into two blocks: warm-up and experimentation. The activities in the first block aim to get students to 'let their hands loose' through activities that lead them to sketch their thoughts directly, regardless of perspective, detail, or quality, just flowing. The activities in the second block seek to make the students experiment with different sketching techniques without fear of making mistakes, thinking and reflecting about the process and not just about the final result, and knowing that if one sketch does not achieve the desired result, they can do more.

2.2 Context and Participants

The TSC workshop was applied and assessed by the multidisciplinary team in an educational environment with end-users. Specifically, in the 'Artistic Expression' subject of the Engineering in Industrial Design and Product Development degree from the School of Engineering and Architecture (EINA) of the University of Zaragoza, taught in the first year and compulsory for all students. The subject deals with different representation techniques of industrial products. A course participated in the study; a total of 84 participants aged 18–22 years applied the TSC workshops to develop their sketching skills.

2.3 TSC Application

TSC was applied during the chiaroscuro practices on three sessions of three hours each. To guide the students during the workshop properly, the 84 students were divided into four groups of 21 members. Each of these sessions (twelve in total) were guided by two multidisciplinary team members and were accomplished following the two general blocks mentioned. The first block is called warm-up-block; it lasts 90 min and consists of the following phases:

- Unblock activity: It is a straightforward and short workflow whose objective is students to disconnect from the previous class and immerse themselves in the context of sketching.
- Presentation: The aim is to present and explain some theoretical aspects of the chiaroscuro drawing technique to be used.
- Warm-up activity: It is an activity whose objective is to begin to experiment and test with the drawing technique.
- Initial sketch: It is aimed to fit the shape of the industrial product chosen by the student making initial sketches.

This is followed by a break for the students, while the teachers photocopy the initial sketches developed by the students. Then, the second block, called experimentation-block, begins. This block lasts 90 min and consists of the following phases:

- Ctrl-Z: It is an activity whose aim is that students can experiment without fear, trying and ‘dirtying’ the paper, having the possibility of ‘undoing’ the actions. For this, they use the photocopies of their initial sketches.
- Inspiration presentation: The aim is to show some examples of sketches with the explained drawing technique, highlighting that ‘less is more’ and that they should not look for hyperrealism.
- Final sketch: During this time, students develop their final sketch from the initial sketch, synthesizing all the knowledge and experiences learned during the session. Meanwhile, the teacher provides feedback to help students reflect and discover themselves.

Table 1 shows the application of TSC in the three chiaroscuro sessions:

Table 1. Application of think-create-sketch (TCS).

TSC	First session	Second session	Third session
Unblock activity (10 min)	Thirty circle challenge: Convert as many circles as possible into recognizable objects. Draw what you have in mind, regardless of perspective, or quality, flowing	To warm the fingertips, the back as a canvas: Draw with the finger on the back of a classmate while capturing what he/she perceives. Mute!	Start smudging to colour a sketch quickly (can draw outside lines). Then apply layers of markers and pencils to create shadows. Use pastels for the lights
Presentation (15 min)	Explanation, tips, and short exercises. Chiaroscuro drawing technique: pencils	Explanation, tips, and short exercises. Chiaroscuro drawing technique: pastels	Explanation, tips, and short exercises. Chiaroscuro drawing technique: markers

(*continued*)

Table 1. (*continued*)

TSC	First session	Second session	Third session
Warm-up activity (25 min)	Templates and canvas to make gradients, colour palettes, and pencil patterns	Templates and canvas to make spheres and cubes in gloss and matte finish; scratch and smudge with pastels	Group sketching: Redesign a water bottle, salt shaker, vase, or air freshener in groups. Use drawings, titles, and callouts, being mandatory not to speak
Initial sketch (25 min)	Composition and shape sketches with pencils		
Ctrl Z activity (20 min)	Experimentation of chiaroscuro with pencils on photocopies	Experimentation of chiaroscuro with pastels on photocopies	Experimentation of chiaroscuro with markers on photocopies
Inspiration presentation (10 min)	Examples of chiaroscuro sketches using pencils	Examples of chiaroscuro sketches using pastels	Examples of chiaroscuro sketches using markers
Final sketch (60 min)	From the initial sketch and experimentation applying the corresponding technique		

Finally, a short closing session was conducted, in which a self-assessment, a survey, and an exercise of 'internalise and simplify' were developed. In the self-assessment, each student reflected and assessed her/his work and the work of another classmate. The survey was distributed among the students to find out their perceptions. During the exercise of internalise and simplify, students were challenged with the following task: Imagine you are in a meeting, and you have to show the rest of the team a product in 10 min. How would you do it? In this manner, the students reflected on the product sketches made in the previous weeks and the techniques and knowledge they had learned (Think). They synthesised and simplified this learning to make a sketch in just 10 min (Sketch). Thus, they developed a 'solution' to the challenge (Create).

2.4 Assessment

During the application, the multidisciplinary team acted as evaluators in the field (specifically three members who acted as lecturers). They assessed the use of TSC by students through a survey, as well as observation, field notes, and periodic internal discussions [24]. In this manner, Xassess is the general framework used for the assessment; Xassess is an evaluation methodology that merges qualitative and quantitative approaches and is centred in multidisciplinary teams [25].

Survey: Individual surveys were conducted, using questionnaires with open and closed questions in the Google Forms platform. The purpose of this survey was to collect scores and feedback about the TSC from students. The survey was divided into five sections. The first 'control questions', which included questions about what previous drawing training had the participants or what blocked them before drawing. The second section, 'development of the TSC workshops', which had questions related to the utility of establishing the classes in phases and the usefulness of these phases. The third 'workshops contributions' contained questions about the contributions of each phase, the drawing techniques, and skills developed. The fourth section, 'workshops improvements', included questions to discover improvements proposed by the participants. Finally, the fifth section, 'sketching training', had questions to know the participants' interest in sketching training.

The resulting data were exported to MS Excel. The closed questions (quantitative) were examined using descriptive statistics and visual graphics. These graphics were made with the Python 3.8 language and the Pandas, Matplotlip, and Seaborn libraries. The open questions (qualitative) were manually coded and grouped according to similarities in the reflections made by the students. Thus, Sect. 3 presents quantitative graphs as well as verbatim quotations that support the assessment.

Observation, field notes, and periodic internal discussions: During the observation, the professors collected field notes which were shared in periodic internal discussions of 25 min at the end of each session (twelve in total). These annotations allowed discovering the key features and contributions of the TSC workshops, collected in the Discussion Section.

Thus, the assessment allows checking to what extent the TSC workshops are integrated into the curriculum (1), to what extent the workshop process is suitable for the students (2), and how it broadens their knowledge for their future (3). In this manner, the results and the main contributions of this study follow this three items structure.

3 Results and Discussion

This section discusses the results obtained on the assessment and the lessons learned to apply TSC workshops to improve students' skill of expression through sketching.

3.1 Incorporation and Adaptation to the Curriculum

According to Calavia et al. [16], incorporation and adaptation to the curriculum are the first premises to consider when developing a material to ensure its viability in the classroom. TSC is adapted to the subject in timing and scope for two reasons. The first and straightforward reason is that, in line with Blanco et al. [23], creating a multidisciplinary team from the beginning make it easier to adapt TSC to the environment.

The second reason is that these workshops are justified in the general subject structure. The course begins with the first block of understanding reality (proportions, scales, etc.), then the chiaroscuro block is found, and finally, it moves towards the third block of formal exploration, i.e. the subject moves from 'what is' to 'what can be'. There is a pathway to move students from something tangible that can be represented towards divergent thinking that leads them to create and develop new forms. Thus, the second block of chiaroscuro, where the TSC workshops are framed, is in the middle and serves as a link between the two blocks. Therefore, applying the approach of the TSC workshops in this block allows students to obtain small knowledge pills that 'open' their minds and aid them to assimilate new resources for action, facilitating the transition between the three blocks of the subject.

Additionally, starting with a more convergent block and ending with a more divergent one makes sense because more than 90% of the students who participated in this study had only technical drawing training. This implies that most of them indicated that what they found most difficult when starting to draw freehand was 'not using ruler and compass'.

It is important to note that these are students who start from convergent thinking, using the left brain to achieve the solution. They need to develop divergent thinking, using the right brain to foster creativity and generate many solutions, since this models them as designers [26]. As novice designers, students need to be trained with methods such as TSC workshops that lead them to develop their own design patterns, accompanying them in this transition.

3.2 Valuation of the TSC Workshops

The students assessed and reflected on the contributions of each of the phases of the TSC workshops (Fig. 1).

- Students noted that the unblock activities helped them 'to break the ice and relax', 'to gain confidence to face the following activities', and 'to stimulate their minds and feel more creative'.
- The presentations were appreciated for the 'to know and understand the techniques', as well as 'to be able to see other examples for inspiration'.
- The warm-up activities are seen as 'direct application of theory' that allow 'discovering and experimenting with the new technique to gain fluency'.
- The experimental activities allowed them 'to discover what works and what does not', 'to try freely and without fear of damaging the end', 'to discover by trial and error'.
- Finally, the making of the final sketch was 'the manner of reflecting all the previous phases' while receiving 'feedback and advice to open the mind and improve the work'.

Regarding the survey item about what phases were the most useful (Fig. 1), it can be seen that the experimental activities were the most highly valued. This is understandable because the students relaxed and openly experimented without fear of failure, under the slogan of 'learning by doing and failing' [27]. In contrast, the presentations were the least chosen by students. This is reasonable since, although the presentations were very visual, they are a typical resource in the classroom, and the student does not participate directly as in the other activities.

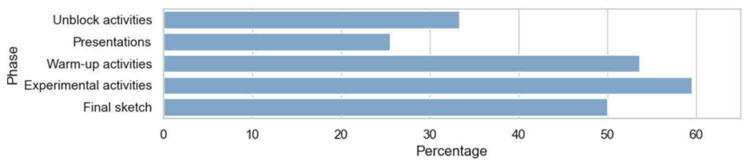


Fig. 1. Phases selected as the most useful by students on percentage (multiple choice question).

Similarly, in response to the question of 'Is it useful to establish the 3 h of class in phases?' they answered positively almost unanimous (97.6%). Students indicated that it was useful following and understanding the process 'it is more enjoyable and interesting, if not it is tiring and monotonous', 'without this distribution, I might have completed the tasks faster, but I would not have known the purpose of the practices'.

However, some students indicated that they would have liked to have more time to complete their final sketch ‘because it is what counts towards our grade’ ‘so we do not have to finish this at home’. These reflections have to do with traditional systems based on extrinsic motivators because they perceived as insufficient the time given for the final sketch, which is assessed with a quantitative mark, sensing the evaluation separate from learning. This is a tough matter, but we align with Sternberg and Lubart [28] about the necessity of devaluing the importance of final marks. We believe that the adoption of workshops such as the proposed could mitigate this phenomenon.

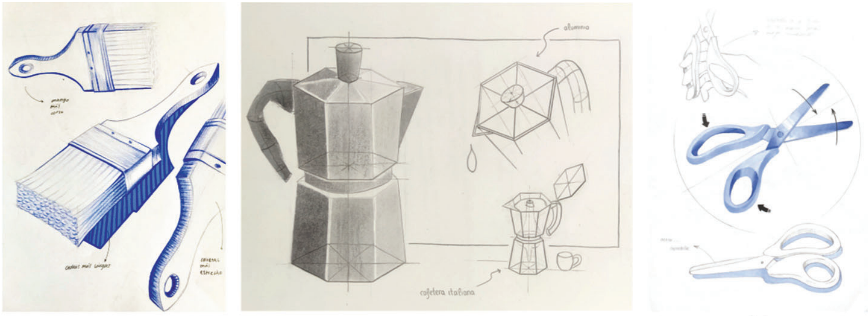
We focus on students assimilating the concept of thinking about the process and not only about the final result, in line with Kleon [29], and supporting them with continuous feedback. This concept match with the type of drawing that is expected in the subject; they should not achieve hyperrealism finishes but process sketches that include what is necessary for their interpretation (indications of use, materials, arrows, calls, cuts, dimensions, etc.). In this manner, they can develop, externalise, record, and communicate their thoughts and ideas during the Design Thinking process, in accordance with Gryaditskaya et al. [14].

It is proposed that to enhance this approach in future applications, in the next course, students document the entire process up to the final sketch (versions, experimentations, initial sketches, etc.), together with a reflection on decision making. Likewise, it is proposed to add a mandatory final reflection phase at the end of each session so that students can see and learn from the work of their colleagues.

Valuation of the Drawing Techniques. Regarding the three techniques used to work on chiaroscuro, 100% of the students admitted that they were suitable for ‘learning to add volume to our sketches’. Specifically, of the pencil technique they appreciated that ‘a lot can be done with a very simple material’ and its usefulness to ‘modulate the line’. Likewise, this technique implied that most of the students reflected on the importance of ‘understanding that not everything should be painted’ and ‘not to fill the paper’; this is essential to achieve fresh finishes (Fig. 2a).

About the pastel technique, they appreciated that it allowed them ‘to give dynamism to my drawings’ as well as ‘to spot and enjoy’ and ‘to cover large surfaces in a short time’. However, some students pointed out that ‘it did not contribute anything to me’ ‘I think it is more focused on artistic drawing’, and some even commented on the possibility of removing it. Thus, it is necessary to work on getting all students to understand it as a technique to provide volume and colour quickly, emphasizing the use of the least amount of material, and thinking about what is essential and what can be omitted. There is no interest in obtaining a perfect realistic render with pastels (see Fig. 2b). However, consideration could be given to changing the subject’s name from ‘Artistic Expression’ to (for example) ‘Expression through sketching’ to avoid the association with the art and preconceived ideas.

Finally, regarding the marker technique, they appreciated ‘achieving more professional results’ as well as ‘surprisingly matte and glossy finishes of plastics’. Likewise, this technique implied that most of the students reflected on the importance of ‘thinking well before painting because the marker cannot be removed’. This is fundamental because before sketching a product, it is important to think and plan; for example, in this case (Fig. 2c), the direction of the light for highlights and shadows.



(a) (b) (c)

Fig. 2. Examples of sketches using (a) pencils, (b) pastels, and (c) markers.

During the sessions, we insist on ‘where you cannot achieve with one technique, apply another’. However, we consider that in future applications, it would be interesting to develop the last practice to combine the three techniques. In addition, the group sketching activity during the third session worked particularly well because they used only the sketch as a means of communication (Fig. 3); so it would be interesting to implement more group activities. Training in sketching quickly and collaboratively is fundamental to their future because it will allow them to express themselves, foster new ways of communication, and promote creative proposals.

Fig. 3. Group sketching activity.

3.3 Broadening Knowledge

All these experiences led students to value the following statements positively, as shown in Fig. 4. These results support our hypothesis about the utility of the TSC workshops in helping students to unblock themselves to communicate through the sketch. In addition, the students perceived that the workshops were useful to achieve the subject contents in relation to chiaroscuro and well-balanced compositions. They also highlighted the improvement in their ability to think more about the process and less about the end result. Therefore, according to the students’ view and considering that sketching stimulates creative thinking [15], the workshop contributes to fostering divergent thinking, enabling students to think creatively.

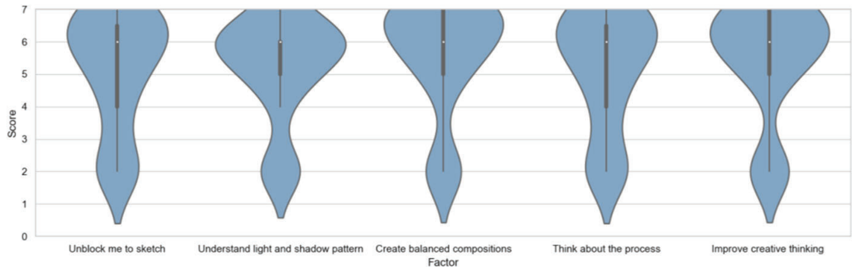


Fig. 4. Assessment of the statements. Likert scores range from 0 (minimum valuation) to 7 (maximum valuation).

This learning is visible in the internalise and synthesise exercise, in which they applied all the acquired knowledge in a condensed manner in just 10 min. Results are quick and fresh (Fig. 5), including elements learned during the subject such as hidden lines, line thickness, background, traces, arrows, annotations, or dimensions.

Fig. 5. Examples of the internalise and synthesise exercise.

Finally, to ascertain the satisfaction and the degree of interest awakened in the students, we posed the question of whether these types of workshops to foster sketching are interesting for their training and whether they would like to broaden their knowledge or information in the future. As shown in Fig. 6, the assessments are positive; the average is 6.4 ± 0.7 and 6.2 ± 0.9, respectively.

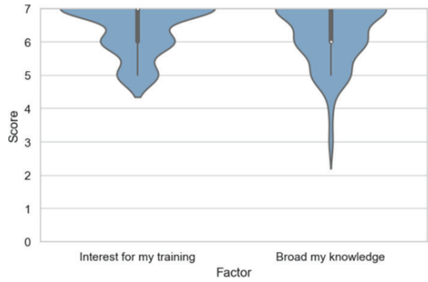


Fig. 6. Assessment of perceived interest and broadening of knowledge. Likert scores range from 0 (minimum valuation) to 7 (maximum valuation).

In order to inquire about the workshop contributions from the teaching perspective, five indicators are identified on the subject's teaching guide related to the learning achievements. First, according to teacher's perspective, the 'agility' of the students was improved thanks to the fluency of the process and the deadlines established in each session. This agility connects with the second item, the increase in 'collaboration'; all groups of students showed an unanimous aptitude to participate in the activities, with an open and fresh initiative that uninhibited them, improving the third indicator, enjoyment. The atmosphere created in the workshops was favourable, and the 'enjoyment' during the activities was tangible among all the actors involved, improving teacher-student and student-student relations. This effect is also reflected in the fourth item, the 'result of the evaluation of the teaching activity', where teachers had a 'positive distinction'. Finally, the academic marks were positive; however, no substantial changes was observed from previous courses. Perhaps this is due to the fact that, as mentioned above, students had less time for the exercise being assessed.

In sum, we can reaffirm that the skill to express oneself through the sketch is fundamental in the training of engineers, especially in the case of design specialists, in line with Hilton et al. [6]. This skill requires further promotion and training throughout the degree to enable future designers to use sketches as a means of communication in their work teams, without the need to use 3D modeling or rendering programs until later or final stages. Thus, using the TSC workshops is not a unique solution but a step towards improving these concepts in future designers' training.

4 Conclusions

This paper proposes the Think-Sketch-Create (TSC) workshops to train future designers in sketching so that they are able to express their thoughts and ideas in work teams. For the workshop development, a multidisciplinary team (formed by specialists in design, art, architecture, creativity, and technology) worked together, focusing on a teaching intervention that leads students to experiment, far from trying to achieve hyperrealism or perfect finishes. As a result, TSC is embodied in practical workshops, in which students experiment with different sketching techniques, thinking and reflecting about the process and not just about the final result. TSC was assessed quantitatively and qualitatively through its application in a compulsory subject of the Engineering in Industrial Design and Product Development degree, with 84 university students.

The results of the experience allow us to affirm the integration of the TSC workshops in the subject, with it being possible to apply the same scheme in other classes. The previous multidisciplinary work, as well as the structure of the subject (from convergent to divergent thinking) implied that TSC was naturally integrated. Additionally, the assessment evidences the effectiveness of the workshop for the proposed objectives; the students openly experimented, thought about the process, learned chiaroscuro techniques, and understood that they should not achieve hyperrealism finishes. Thus, the TSC workshops are a first step that aids future designers to unblock themselves to use sketching as a means of communication during the design process. Consequently, this study reflects the potential of fostering sketching skills and the need to develop actions for their continuous training.

References

1. Daly, S.R., Adams, R.S., Bodner, G.M.: What does it mean to design? A qualitative investigation of design professionals' experiences. J. Eng. Educ. **101**(2), 187–219 (2012)
2. Tulsi, P., Poonia, M.: Expectations of industry from technical graduates: implications for curriculum and instructional processes. J. Eng. Educ. **28**(4), 42–49 (2015)
3. Tuning, P.: Tuning educational structures in Europe. Informe final. Proyecto piloto. Fase 1. Universidad de Deusto, Bilbao (2003)
4. Booth, J.W., Taborda, E.A., Ramani, K., Reid, T.: Interventions for teaching sketching skills and reducing inhibition for novice engineering designers. Des. Stud. **43**, 1–23 (2016)
5. Eissen, K., Steur, R.: Sketching: Basics. Bis Publishers, Amsterdam (2012)
6. Hilton, E.C., Paige, M., Williford, B., Li, W., Hammond, T., Linsey, J.: Improving the sketching ability of engineering design students. In: Proceedings of the 21st International Conference on Engineering Design, vol. 9, pp. 217–224 (2017)
7. Brown, T.: Design thinking. Harv. Bus. Rev. **86**(6), 84 (2008)
8. Carroll, M.P.: Shoot for the moon! The mentors and the middle schoolers explore the intersection of design thinking and STEM. J. Pre-Coll. Eng. Educ. Res. (J-PEER) **4**(1), 14–30 (2014)
9. Dorst, K., Cross, N.: Creativity in the design process: co-evolution of problem–solution. Des. Stud. **22**(5), 425–437 (2001)
10. Howard, T.J., Culley, S.J., Dekoninck, E.: Describing the creative design process by the integration of engineering design and cognitive psychology literature. Des. Stud. **29**(2), 160–180 (2008)
11. Mosely, G., Wright, N., Wrigley, C.: Facilitating design thinking: a comparison of design expertise. Thinking Skills Creativity **27**, 177–189 (2018)
12. Razzouk, R., Shute, V.: What is design thinking and why is it important? Rev. Educ. Res. **82**(3), 330–348 (2012)
13. Brown, T., Wyatt, J.: Design thinking for social innovation. Dev. Outreach **12**(1), 29–43 (2010)
14. Gryaditskaya, Y., Sypesteyn, M., Hoftijzer, J.W., Pont, S.C., Durand, F., Bousseau, A.: OpenSketch: a richly-annotated dataset of product design sketches. ACM Trans. Graph. **38**(6), 232–241 (2019)
15. Van der Lugt, R.: How sketching can affect the idea generation process in design group meetings. Des. Stud. **26**(2), 101–122 (2005)

16. Calavia, M.B., Blanco, T., Casas, R.: Fostering creativity as a problem-solving competence through design: think-create-learn, a tool for teachers. Think. Skills Creativity **39**, 100761 (2021)
17. Kleiman, P.: Towards transformation: conceptions of creativity in higher education. Innov. Educ. Teach. Int. **45**(3), 209–217 (2008)
18. Verstijnen, I.M., van Leeuwen, C., Goldschmidt, G., Hamel, R., Hennessey, J.M.: Sketching and creative discovery. Des. Stud. **19**(4), 519–546 (1998)
19. Jenny, P.: Técnicas de dibujo. Gustavo Gili, Barcelona (2013)
20. Norp, B., Van Hoek, E.: Industrial design sketching in practice. In: 21st International Conference on Engineering and Product Design Education (E&PDE), pp. 1–10 (2019)
21. Worinkeng, E., Summers, J.D., Joshi, S.: Can a pre-sketching activity improve idea generation? In: Abramovici, M., Stark, R. (eds.) Smart Product Engineering. Lecture Notes in Production Engineering. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-30817-8_57
22. Edwards, B.: Drawing on the right side of the brain. In: CHI'97 Extended Abstracts on Human Factors in Computing Systems, pp. 188–189 (1997)
23. Blanco, T.: Metodologías de diseño como plataforma para la x-disciplinaridad en proyectos tecnológicos: surfing disciplines. Doctoral dissertation, Universitat Politècnica de València (2016)
24. Lodico, M.G., Spaulding, D.T., Voegtle, K.H.: Methods in Educational Research: From Theory to Practice, vol. 28. Wiley, San Francisco (2010)
25. Blanco, T., Berbegal, A., Blasco, R., Casas, R.: Xassess: crossdisciplinary framework in user-centred design of assistive products. J. Eng. Des. **27**(9), 636–664 (2016)
26. Blanco, T., López-Forniés, I., Zarazaga-Soria, F.J.: Deconstructing the Tower of Babel: a design method to improve empathy and teamwork competences of informatics students. Int. J. Technol. Des. Educ. **27**(2), 307–328 (2015)
27. Bain, K.: Lo que hacen los mejores profesores universitarios. PUV, Valencia (2005)
28. Sternberg, R.J., Lubart, T.I.: La creatividad en una cultura conformista: un desafío a las masas. Paidós Ibérica, Madrid (1997)
29. Kleon, A.: Aprende a promocionar tu trabajo: 10 recursos para artistas, diseñadores y creativos. Gustavo Gili, Barcelona (2016)

4. Discusión

Esta tesis nace con el objetivo de avanzar en nuevas estrategias para fomentar competencias transversales en los entornos educativos; especialmente la creatividad, entendida como un proceso de resolución de problemas. Para alcanzarlo se establecieron cinco objetivos específicos dirigidos a: definir un marco teórico basado en factores para diseñar desarrollar y evaluar nuevas estrategias que ayuden a fomentar la creatividad (OBJ1); crear nuevas estrategias metodológicas basadas en el *Design Thinking* para promover la creatividad en el alumnado (OBJ2) y en el futuro personal docente (OBJ3); y aprovechar el campo de las TIC (OBJ 04) y del *sketching* (OBJ 05) como herramientas de aprendizaje.

La consecución de estos objetivos ha proporcionado una serie de contribuciones al conocimiento (expuestas en cada estudio presentado) que se sintetizan en esta sección. Estas contribuciones se estructuran desde las más conceptuales, relativas a las aportaciones teóricas (4.1) y a las nuevas estrategias desarrolladas (4.2), hasta las más prácticas relativas a la aplicación de las estrategias (4.3). Asimismo, se incluyen las limitaciones de los estudios realizados durante la tesis y se incluyen las posibles líneas futuras de investigación (4.4).

4.1. Contribuciones teóricas

Los seis estudios que se presentan en esta tesis responden al objetivo general de investigación, avanzando en el conocimiento a partir del diseño, desarrollo y validación de nuevas estrategias para los entornos educativos. Diseñar un recurso que fomente competencias transversales, concretamente la creatividad como resolución de problemas, no es una tarea directa, y su propósito se debe asentar en bases científicas.

Existen métricas para analizar cómo de creativa es una persona a partir de indicadores como el número o la calidad de las ideas (Ibáñez, 1998), pero ¿de qué sirve que un estudiante tenga grandes ideas si su capacidad de comunicación y de trabajo en equipo es baja y no puede transmitirlas? ¿o si el proceso creativo no es razonado? Por ello, no se consideró medir la "cantidad" de creatividad en el alumnado a partir de la aplicación de las estrategias, sino asegurar que las nuevas estrategias cumplen unos factores determinados para establecer unas condiciones óptimas que guíen al alumnado hacia el desarrollo de competencias transversales.

Así, esta tesis establece un marco teórico basado en 15 factores para diseñar desarrollar y validar nuevas estrategias que ayuden a fomentar la creatividad (objetivo 1). Estos factores provienen de una revisión bibliográfica de acuerdo con Lodico et al. (2010), empleando el término de búsqueda "creatividad" en combinación con "factores", "aspectos", "evaluación", "teoría", "educación", "enseñanza" y "materiales", y seleccionando aquellas publicaciones que describen características de la creatividad, conceptos relacionados con el proceso creativo, cómo introducir la creatividad en educación o cómo enseñar creatividad. A partir de un proceso de análisis y combinación, se aislaron 15 grupos temáticos, que son los 15 factores de creatividad que se muestran en la Tabla 2. Estos factores se encuentran organizados de acuerdo con el orden de aparición a la hora de utilizar un recurso didáctico en el aula, y fueron cotejados con expertos del campo del diseño y la educación. Una descripción pormenorizada de esta revisión bibliográfica se puede encontrar en el estudio 1.

Tabla 2. *Factores de la creatividad*

Factor	Definición	Referencias
1. Incorporación al currículo.	Se adapta correctamente al currículo.	(Feldhusen & Treffinger, 1985; Finke et al., 1992; Logan et al., 1980; López, 2008; Şendurur et al., 2016; Sternberg & Lubart, 1997; Torre & Violant, 2006)
2. Practicidad	Los materiales son lógicos, útiles y sensibles a las necesidades del profesorado y alumnado.	(Finke et al., 1992; López, 2008; Şendurur et al., 2016)
3. Novedad	Es original y atractivo.	(Finke et al., 1992; Guilford, 1950; Huidobro & González, 2004; Şendurur et al., 2016; Simonton, 2000; Sternberg & Lubart, 1997; Torrance, 1972)
4. Clima	Busca huir de lo monótono,	(Craft, 2003; Feldhusen & Treffinger, 1985;

	dogmático y tradicional.	Gervilla, 2003; Lewis, 2009; Logan et al., 1980; López, 2008; Peterson, 2001)
5. Estimulación	Ayuda a despertar el interés.	(Craft, 2003; Feldhusen & Treffinger, 1985; Gervilla, 2003; González, 2006; Huidobro & González, 2004; Torre & Violant, 2006)
6. Análisis	Facilita la compresión y entendimiento de conceptos.	(Hennessey & Amabile, 1987; Huidobro & González, 2004; Simonton, 2000)
7. Cooperación	Promueve la comunicación y el trabajo en equipo.	(Amabile, 1998; Gervilla, 2003; Huidobro & González, 2004; Torre & Violant, 2006)
8. Motivación intrínseca	Aumenta la motivación para realizar acciones por uno mismo.	(Amabile, 1998; Craft, 2003; González, 2006; Guilford, 1950; Huidobro & González, 2004; Logan et al., 1980; López, 2008; Simonton, 2000; Sternberg & Lubart, 1997; Torrance, 1972; Torre & Violant, 2006)
9. Participación	Fomenta la participación, acogiendo opiniones, preguntas y respuestas.	(Fasko, 2001; Feldhusen & Treffinger, 1985; Gervilla, 2003; González, 2006; Huidobro & González, 2004)
10. Flexibilidad	Permite cambios o variaciones según las necesidades.	(Finke et al., 1992; Gervilla, 2003; González, 2006; Guilford, 1950; Huidobro & González, 2004; Logan et al., 1980; Simonton, 2000; Sternberg & Lubart, 1997; Torrance, 1972; Torre & Violant, 2006)
11. Incertidumbre	Fomenta la curiosidad, la indagación, la investigación y la experimentación, permitiendo cometer errores.	(Fasko, 2001; Feldhusen & Treffinger, 1985; Gervilla, 2003; González, 2006; Guilford, 1950; Hennessey & Amabile, 1987; Huidobro & González, 2004; Lewis, 2009; Logan et al., 1980; Peterson, 2001; Simonton, 2000; Sternberg & Lubart, 1997; Torrance, 1972)
12. Tiempo de reflexión	Deja tiempos de reflexión.	(Feldhusen & Treffinger, 1985)
13. Divergencia	Permite mirar desde diferentes perspectivas para encontrar más de una solución frente a un problema.	(Feldhusen & Treffinger, 1985; González, 2006; Guilford, 1950; Huidobro & González, 2004; Simonton, 2000; Sternberg & Lubart, 1997)
14. Autoevaluación	Permite la autoevaluación para reflexión y enriquecimiento.	(Gervilla, 2003; Logan et al., 1980; Torre & Violant, 2006)
15. Redefinición	Requiere retroalimentación para redefinir el problema/solución/etc.	(Gervilla, 2003; Guilford, 1950; Torrance, 1972)

4.2. Contribuciones en nuevas estrategias

En base a estos 15 factores, y considerando las necesidades y objetivos expuestos, esta tesis contribuye con nuevas estrategias diseñadas a partir de un equipo de trabajo formado por especialistas de las disciplinas del diseño, la educación y la tecnología:

- *Think-Create-Learn* (TCL) publicada en el estudio 1 (indexado en JCR) y con base en los estudios 2 y 3 (Congreso Internacional y capítulo de libro respectivamente). En respuesta al objetivo 2, TCL es una metodología para apoyar al profesorado en la formación del alumnado en competencias transversales como la creatividad a partir del *Design Thinking.*
- *Think-Create-Teach* (TCT) publicada en el estudio 4 (indexado en JCR). En respuesta al objetivo 3, TCT es una metodología para formar al futuro personal docente en *Design Thinking* con el objetivo de que en su futura labor sean capaces de identificar necesidades y de diseñar materiales didácticos para darles respuesta.
- Tablero basado en *Design Thinking* (*DT-based board*) publicado en el estudio 5 (indexado en JCR). En respuesta al objetivo 4, el tablero es una herramienta para mejorar la implementación y gestión de proyectos de diseño a distancia (aprendizaje remoto) con grandes grupos de estudiantes, a partir de tecnología con una curva de aprendizaje ágil.
- *Think-Sketch-Create* (TSC) publicada en el estudio 6 (indexado en SMG). En respuesta al objetivo 5, TSC es una herramienta para ayudar al alumnado a desbloquearse para expresar sus pensamientos e ideas a través del boceto o *sketching* como medio de comunicación.

Esta tesis proporciona la validación de cada una de estas nuevas estrategias metodológicas en contextos reales. Para ello, se adaptó a cada estudio, la estrategia de evaluación de Xassess (Blanco et al., 2016), utilizando métodos cuantitativos y cualitativos, tal y como se detalla en cada uno de los estudios expuestos en esta tesis. Asimismo, durante el estudio 3 se detallan las 5 dimensiones de Xassess adaptadas a la evaluación de una herramienta en la idiosincrasia del entorno educativo (Figura 8). A continuación, se aporta una pequeña síntesis relacionada con los aprendizajes de cada una de las dimensiones:

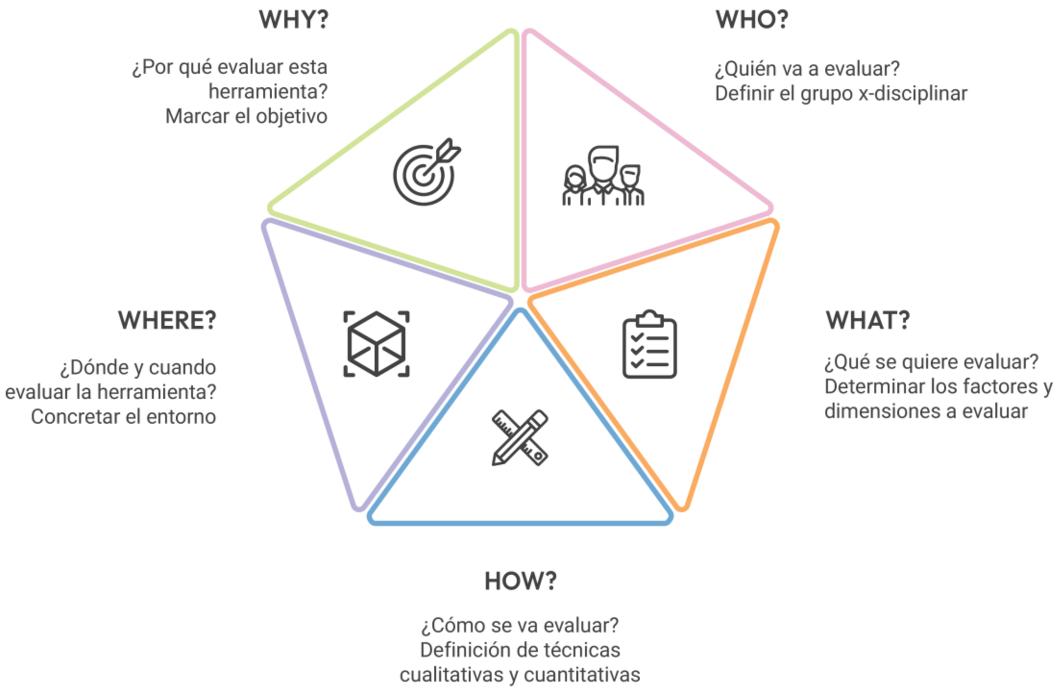


Fig 8. Esquema simplificado de las fases de Xassess

- *When:* Es necesario señalar que, a la hora de evaluar una nueva herramienta en un entorno educativo, ésta debe encontrarse en una fase del proyecto avanzada. Por el contrario, en fases tempranas puede provocar desconfianza o confusión tanto por parte del profesorado como del alumnado, disminuyendo la aceptación de esta.
- *Why:* Es necesario plantear cuáles son los objetivos generales de la evaluación de la herramienta: tomar decisiones, evaluar, seleccionar, analizar, modelar, simular, probar o experimentar (Sim & Duffy, 2003).
- *Who:* Es necesario distinguir entre quién es el objeto de evaluación (a quién evaluamos) y quién es el ejecutor de la evaluación (quién evalúa). Xassess plantea que no solo los evaluadores, sino los equipos x-disciplinares colaboren en la evaluación, orientando esta misma como herramienta estratégica de diseño. Para ello, establecer las motivaciones de cada parte (diseño, educación y tecnología) proporciona una perspectiva global del proyecto, ayuda a mejorar la comunicación y la valoración entre perfiles y contribuye a la definición de los indicadores de evaluación.
- *What:* Es necesario plantear el objetivo principal de validación; en general, coincide con la función principal de la herramienta. Posteriormente, para facilitar el proceso de validación es favorable desglosar en dimensiones de acuerdo con los 15 factores y determinar los indicadores.
- *How:* Una vez definidos los indicadores de evaluación, es necesario plantear la estrategia de evaluación. Xassess propone la triangulación o la combinación como estrategias óptimas, utilizando métodos mixtos (cuantitativos y cualitativos). Esto es fundamental en la evaluación en entornos educativos con docentes y estudiantes, ya que, por ejemplo, los enfoques exclusivamente

cuantitativos o cualitativos tienen debilidades interpretativas, y los enfoques mixtos pueden ayudar a superarlas.

De acuerdo a la evaluación de los 15 factores descritos (Tabla 2) y publicados en el estudio 1, se ha visto que el factor de incorporación y adaptación al currículo es la primera premisa a tener en cuenta a la hora de desarrollar una nueva herramienta para asegurar su viabilidad en el aula. La adaptación de las estrategias desarrolladas en la tesis ha sido facilitada gracias al contexto favorable en el que nos encontramos; evidenciado, entre otros, por docentes sensibilizados con la importancia de un modelo educativo basado en el aprendizaje por competencias, la innovación en educación o la necesidad de aplicar nuevas estrategias metodológicas.

El paradigma constructivista, en el que se sitúa la educación actualmente, implica que el profesorado no sólo utilice métodos expositivos, sino que también trabaje con métodos participativos como el Aprendizaje Basado en Proyectos (Velázquez et al., 2020). En este sentido, tal y como demostró el estudio 4, el Aprendizaje Basado en Proyectos, que se encuentra con frecuencia en los programas de formación, es notablemente favorable para introducir de manera natural las estrategias descritas basadas en el *Design Thinking*.

Para favorecer la integración de una nueva estrategia basada en *Design Thinking* en un contexto donde se está aplicando Aprendizaje Basado en Proyectos, esta tesis identifica algunas similitudes y diferencias a considerar. Por un lado, el Aprendizaje Basado en Proyectos es un método en el que el alumnado aplica, desarrolla y aprende conceptos a través del trabajo colaborativo mientras resuelve un problema que puede o no estar establecido (Blumenfeld et al., 1991; Chang & Lee, 2010; Kokotsaki et al., 2016). Este método promueve la resolución de problemas, la comunicación, el trabajo en equipo y el liderazgo (Häkkinen et al., 2017; Tsybulsky & Muchnik-Rozanov, 2019). Así, *Design Thinking* y Aprendizaje Basado en Proyectos comparten un enfoque sistemático centrado en encontrar soluciones innovadoras a los problemas; ambos adoptan un enfoque de aprendizaje constructivista (Dag & Durdu, 2017); y ambos son solicitados para la enseñanza y el aprendizaje basados en competencias (Goldman & Zielezinski, 2016; Stokholm, 2014).

Por otro lado, la figura 9 muestra las diferencias entre ambos campos agrupadas por categorías, derivadas de los estudios de Elwood et al. (2016), Goldman & Zielezinski (2016), McIntosh (2012), Melles et al. (2015) y Stokholm (2014). Como se observa, el Aprendizaje Basado en Proyectos parte de un problema o pregunta planteada por el profesorado o el alumnado, muchas veces relacionado con el currículo, y establece una ruta parcialmente predefinida. En contraste, el *Design Thinking* permite al alumnado identificar, formular y enmarcar problemas basados en sus propias investigaciones y experiencias personales, para luego responder estos problemas a través de estrategias no lineales, involucrando a personas y sin tener una meta en mente. Aunque ambas perspectivas involucran habilidades similares, el *Design Thinking* se enfoca más en el aprendizaje experiencial y el desarrollo de habilidades relacionadas con el planteamiento e identificación de problemas, la empatía y el pensamiento creativo, mientras que el Aprendizaje Basado en Proyectos atiende más al aprendizaje de conocimientos y habilidades como la gestión y el desarrollo de proyectos.

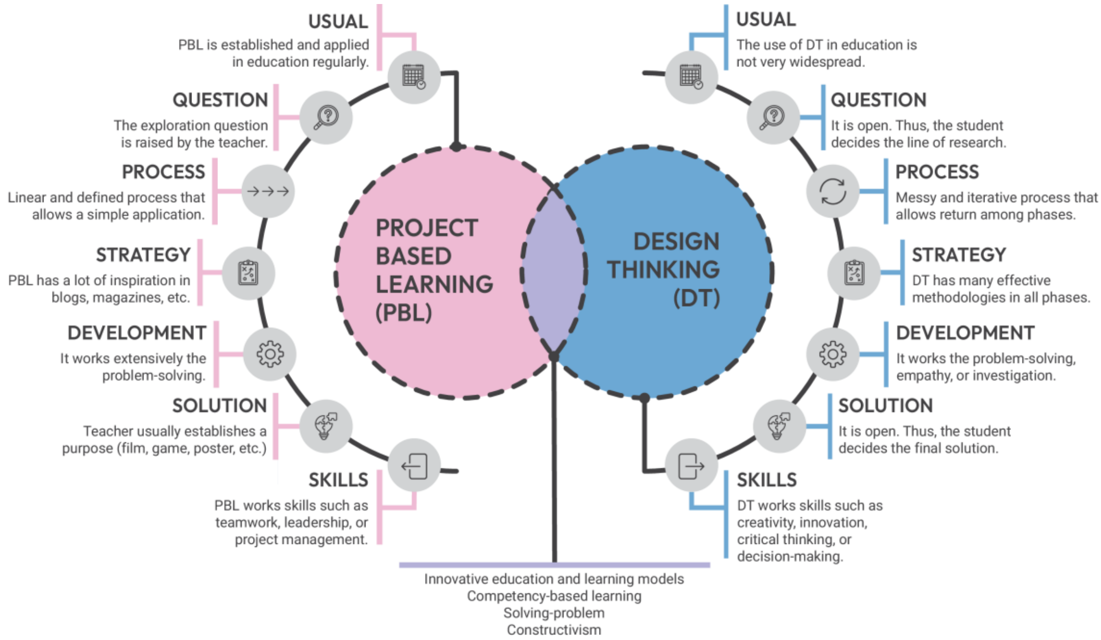


Fig 9. Características, diferencias y similitudes entre Aprendizaje Basado en Proyectos y Design Thinking.

Otro punto notable en la incorporación y adaptación de las nuevas estrategias es la entrada en vigor de la nueva ley educativa Ley Orgánica 3/2020, de 29 de diciembre, por la que se modifica la Ley Orgánica 2/2006, de 3 de mayo, de Educación (LOMLOE). Entre otros principios, esta ley resalta las necesidades de adecuar el sistema educativo al cambio, desarrollar la competencia digital, valorar la diversidad y propiciar un aprendizaje por competencias, autónomo, significativo y reflexivo en todas las materias.

Un ejemplo de ello es que según el artículo 4 de la LOMLOE (2020, p. 122882) "La enseñanza básica (...) debe procurar al alumnado los conocimientos y competencias indispensables para su desarrollo personal, para resolver situaciones y problemas de los distintos ámbitos de la vida, crear nuevas oportunidades de mejora, así como para desarrollar su socialización, lograr la continuidad de su itinerario formativo e insertarse y participar activamente en la sociedad en la que vivirán". En este sentido, el artículo 26 de la LOMLOE (2020, p. 122888) establece que "Con objeto de fomentar la integración de las competencias, se dedicará un tiempo del horario lectivo a la realización de proyectos significativos para el alumnado y a la resolución colaborativa de problemas, reforzando la autoestima, la autonomía, la reflexión y la responsabilidad".

Asimismo, la normativa que rige la atención a la diversidad en la comunidad autónoma de Aragón, a partir de los principios establecidos en la LOMLOE (2020), el Decreto 164/2022, de 16 de noviembre, que modifica el Decreto 188/2017, de 28 de noviembre, por el que se regula la respuesta educativa inclusiva y la convivencia en las comunidades educativas de la Comunidad Autónoma de Aragón (BOA de 24 de noviembre de 2022), establece como uno de sus principios generales la formación y el impulso de prácticas innovadoras en relación con las metodologías aplicadas al proceso de aprendizaje, que promuevan la autonomía de todo el alumnado y faciliten la adquisición de las competencias clave, fomentando la realización de proyectos y experiencias inclusivas. De este modo, se resalta la importancia de trabajar en incluir metodologías participativas y de corte constructivista como es el *Design Thinking* para ayudar al alumnado a conseguir un aprendizaje más significativo en todos los niveles, desde la Educación Infantil hasta Bachillerato. Por tanto, se puede afirmar que los estudios de esta tesis contribuyen a mejorar cuestiones recogidas en la normativa actual.

Así, los objetivos descritos en la normativa se alinean con el cometido de los estudios (1-6) de esta tesis; la importancia de adecuar los sistemas educativos a las situaciones de cambio e incertidumbre, formando al profesorado y alumnado en la capacidad de adaptación y en la creatividad como resolución de problemas. Ello demuestra que la concepción de esta tesis se adelantaba a la normativa vigente y que las nuevas estrategias constituyen un mecanismo concreto y válido para ayudar al profesorado a poner en práctica lo que indica la ley.

Finalmente, cabe señalar que un medio relevante para asegurar la incorporación y adaptación de las estrategias desarrolladas al entorno real, de acuerdo con Blanco et al. (2016), fue el hecho de que no estuviesen diseñadas desde un grupo aislado, sino en colaboración con otras disciplinas y considerando premisas educativas desde el inicio. Tal y como se observa en los estudios presentados (1-6), en general, el equipo x-disciplinar estaba formado por especialistas en diseño, tecnología y educación. Por un lado, el equipo de diseño para aportar las bases y fundamentos de la disciplina del diseño y el *Design Thinking*, así como la perspectiva global del proyecto, y el diseño de materiales de calidad. Por otro lado, el equipo de tecnología para aportar las bases y las oportunidades de la tecnología. Por último, el equipo de educación para aportar y establecer las bases en didáctica y pedagogía, premisas educativas, y amplia experiencia en formación al futuro personal docente.

Así, la perspectiva x-disciplinar ha sido clave en este sentido, contribuyendo claramente al diseño y análisis de nuevas estrategias más cercanas a las motivaciones y necesidades de cada una de las partes involucradas, y sacando a la luz cuestiones emergentes antes no cubiertas (Blanco, 2016).

4.3. Contribuciones prácticas de las metodologías

En base a los 15 factores aportados en el estudio 1, las nuevas estrategias presentadas y validadas en los estudios (1-6) aportan valor práctico al entorno educativo en los siguientes términos:

Practicidad de los materiales

Un indicador de la calidad de los materiales desarrollados fue que tanto docentes como estudiantes mostraron una actitud positiva hacia los mismos. Por ejemplo, en el estudio 1 (TCL aplicado en estudiantes de secundaria) el profesorado aseguró que el material era novedoso y cuidado, y valoraron positivamente el peso de la disciplina del diseño "el material hace que a los alumnos les entre curiosidad (...) esto se puede hacer de forma austera y no se hubiesen obtenido los mismos resultados. Las cosas no son lo que cuentas, sino cómo lo cuentas". Así, la influencia del diseño en las metodologías y los materiales se encontró relevante y positiva. Uno de los principales objetivos del *Design Thinking* y de los procesos de desarrollo del diseño es adaptar los materiales tanto al contexto como a los diferentes usuarios, añadiendo valor connotativo y denotativo. Asimismo, gracias a las posibilidades que ofrecen las nuevas tecnologías para crear y compartir contenidos (Henriksen et al., 2016; Lombardi, 2007), en el estudio 5 la metodología fue soportada digitalmente, lo que permitió su difusión y aplicación durante la situación de COVID-19.

En todos los estudios presentados la opinión acumulada de docentes y estudiantes sobre el material fue positiva; no obstante, cabe señalar que algún estudiante indicó que "algunas actividades fueron realmente laboriosas". Esto es comprensible, considerando que el alumnado debe ser plenamente activo y participativo, lejos de la postura pasiva adoptada en la metodología tradicional (Lee & Erdogan, 2007; McMullan, 2016; Nguyen et al., 2017; Qi, 2017; Zhang & Guo, 2017; Zhao & Meng, 2015) a la que estaban habituados.

Clima cálido como estímulo para la participación

En los estudios desarrollados, una de las tareas preferentes fue establecer puentes entre docentes y estudiantes, con el objetivo de que el alumnado se relajase y se involucrase en las actividades de manera desinhibida. Para ello, las estrategias desarrolladas establecieron un clima confortable basado en la comunicación docente-estudiante, estudiante-estudiante y estudiante-docente, utilizando las propias metodologías como herramienta de comunicación. Asimismo, las propias estrategias inciden al profesorado en que deben tolerar el error, centrándose en el proceso y no tanto en el resultado final, y animando al alumnado con mensajes como "nada está mal". Este tipo de relación entre docente y estudiante trae beneficios significativos para el alumnado; como afirman diferentes autores, un ambiente psicosocial adecuado potencia el establecimiento de un ambiente didáctico que promueva y anime al alumnado a interactuar y participar con opiniones, preguntas y respuestas, incrementando su aprendizaje académico (Thapa et al., 2013; Vass, 2017; Voelkl, 1995).

En este punto, cabe señalar el estudio 5 enmarcado en la situación de COVID-19. Bajo este contexto, se aprovechó la oportunidad coyuntural para experimentar *Design Thinking* y TIC; así se adoptó la metodología de TCT (para formar al futuro personal docente) al aprendizaje remoto. El uso del tablero basado en *Design Thinking* integrado en la plataforma Trello (versión 2.1.3, Atlassian, Sidney, Australia) fue especialmente útil para la comunicación y un paso para la transformación digital. La mayoría del futuro personal docente admitió que el proceso de trabajo aplicado durante la asignatura a través de la metodología TCT y el tablero fue mejor que el desarrollado en otras asignaturas durante la pandemia. Esto lo justificaron por tres razones: el proceso de trabajo continuo, la estructura y planificación de la metodología, y la retroalimentación brindada.

Del mismo modo, el profesorado admitió que el tablero les permitió "estar conectados y monitorear el progreso de cada grupo" así como "tener una visión general del proyecto de un vistazo" con una curva de aprendizaje ágil. Esto es notorio para el contexto educativo, ya que algunas soluciones de gestión del aprendizaje pueden ser difíciles de usar porque son abrumadoras, tienen muchas funciones que no siempre se conocen o aplican, y requieren capacitación y tiempo excesivo. Sin embargo, el tablero propuesto es beneficioso para el aprendizaje remoto porque es fácil de usar, flexible y permite organizar proyectos visualmente, simulando una pizarra llena de *post-its*. Esto hace que el alumnado participe activamente a través de las TIC (Schmid et al., 2014), lo que contribuye al desarrollo de competencias digitales, que en el caso del futuro personal docente según Colás-Bravo et al. (2021) son esenciales para alcanzar una ciudadanía digital.

El proceso como núcleo del aprendizaje

Otro de los principales cometidos de las estrategias desarrolladas fue transmitir a estudiantes y docentes la importancia de pensar en el proceso, y no solo en el resultado final, en línea con Kleon (2016). Para ayudar a asimilar este concepto, las metodologías se enfocan en la evaluación y retroalimentación continua durante el proceso, premiando la voluntad de explorar, descubrir e innovar (Erbas & Bas, 2015).

Este punto es claro en el estudio 4, en el que se observó que el proyecto realizado por el futuro personal docente a través de TCT fue visto por el profesorado de la asignatura como "un proceso estructurado, cohesionado, reflexivo y justificado". Esto es especialmente notable en comparación con los informes realizados por el grupo de control vistos como "informes aislados" en los que "solo se valora el resultado final (...) sin considerar el proceso de cómo piensan, detectan el problema y buscan soluciones instruccionales pensando en los estudiantes".

Como resultado de este proceso, los materiales de instrucción (resultado final) desarrollados a través de TCT fueron mejor valorados en los factores de adecuación, uso y creatividad. Así, TCT permitió al futuro personal docente desarrollar materiales didácticos fundamentados y centrados en el ser humano "no hacen un material porque lo han visto en Pinterest, hay un razonamiento y una justificación detrás" (profesorado de la asignatura). Esto se debe principalmente a que TCT (y también TCT) se basa en *Design Thinking*, que involucra un proceso iterativo (fusión de pensamiento divergente y convergente) que promueve la creatividad (Teal, 2010), y se enfoca en comprender conceptos y brindar soluciones centradas en el ser humano (Brown, 2008; Carroll, 2014; Dorst & Cross, 2001; Howard et al., 2008; Mosely et al., 2018; Razzouk & Shute, 2012).

No obstante, cabe señalar que, en este mismo estudio, las tarjetas de actividades directamente asociadas al *Design Thinking* fueron las que más dudas plantearon en el profesorado en formación (futuro personal docente). Esto es comprensible porque no tienen experiencia previa en diseño y no conocen patrones básicos de diseño (Elwood et al., 2016).

Motivación intrínseca más que motivación extrínseca

Las estrategias presentadas en los estudios permiten un ambiente de aprendizaje proactivo, fomentando el proceso de investigación y experimentación, y mostrando que plantear problemas como desafíos aumenta la motivación intrínseca del alumnado, en línea con López (2008) y Amabile (1998).

No obstante, en varios momentos durante la evaluación de los estudios presentados, se puede observar cómo el alumnado se concentró en las calificaciones. Por ejemplo, en el estudio 1, el alumnado de secundaria incidía en cómo sería el examen; o en el estudio 6, el alumnado de ingeniería percibía como insuficiente el tiempo dedicado al dibujo final, valorado con una nota cuantitativa. Esta es una respuesta lógica al sistema establecido y es un asunto complicado; no se puede huir de toda la realidad, pero los estudios presentados se alinean con Sternberg y Lubart (1997) y otros sobre la necesidad de desvalorizar la importancia de las notas como primer motivador extrínseco.

Asimismo, las metodologías se enfocan en hacer comprender al alumnado que el fracaso es una parte esencial del aprendizaje (Freeman et al., 2017) y se apoya al alumnado con retroalimentación continua para la redefinición, incluyendo la evaluación como parte del aprendizaje. Así, según Bain (2005, p.7), el alumnado se forma adecuadamente bajo el lema de "aprender haciendo, e incluso fallando".

Es curioso señalar que este concepto coincide con el objetivo del estudio 6. En este estudio no se pretende que el alumnado logre resultados finalistas y acabados hiperrealistas. TSC busca ayudar al alumnado a desbloquearse para que sea capaz de experimentar y elaborar bocetos que incluyan lo necesario para su interpretación (indicaciones de uso, materiales, flechas, llamadas, cortes, dimensiones, etc.) con el objetivo de que puedan desarrollar, exteriorizar, registrar y comunicar sus pensamientos e ideas durante el proceso de *Design Thinking*, de acuerdo con Gryaditskaya et al. (2019).

Crecimiento del conocimiento

De acuerdo con la UNESCO "La educación de calidad fomenta la creatividad y el conocimiento, garantiza la adquisición de las competencias básicas de lectura, escritura y cálculo, así como de aptitudes analíticas, de solución de problemas y otras habilidades cognitivas, interpersonales y sociales de alto nivel" (UNESCO, 2016). Por tanto, no se trata de sustituir los contenidos por competencias, sino que ambos conceptos se deben nutrir e integrar conjuntamente.

En esta línea, aunque las estrategias desarrolladas en esta tesis (estudios 1-6) se presentan como medio para el fomento de competencias transversales, es fundamental que ayuden al alumnado a adquirir conocimiento y competencias específicas. La secuencia presentada por Acaso y Megías (2017) de Neuroeducación (disciplina que estudia el cerebro durante el proceso de enseñanza-aprendizaje) señala que el aprendizaje solo es posible cuando se despierta la curiosidad y la atención, lo que provoca emoción que es la clave para estimular el aprendizaje (Figura 10). Más concretamente, el aprendizaje sucede cuando algo diferente en el entorno nos despierta curiosidad; esa curiosidad hace fijar nuestra atención sobre ese algo; y la atención nos lleva a desarrollar una emoción sobre ese suceso (Acaso & Megías, 2017). Así, los dos primeros pasos (Figura 10) coinciden con los resultados de los estudios presentados; las metodologías generaron curiosidad y atención al alumnado, ya que les permitieron trabajar de manera diferente. Después, la emoción llegó cuando la teoría se vinculó con el mundo real, y según Gerver (2017), el buen profesorado tiene la capacidad de conectar los conceptos con la vida del alumnado; y cuando el alumnado se emociona por las cosas, las aprende. En línea con Bain (2005), las estrategias propuestas colocan a docentes y estudiantes en una posición de incertidumbre y generan nuevos estímulos, interrogantes y perspectivas que les permiten construir conocimientos útiles y aplicables.

Esto es fundamental en los entornos educativos, pero hacemos hincapié en el estudio 1, en el que el alumnado era de secundaria. En este contexto, es fundamental conectar los conocimientos y conceptos con la realidad de su día a día y con sus intereses, con el objetivo de motivarles y evitar el abandono educativo temprano.

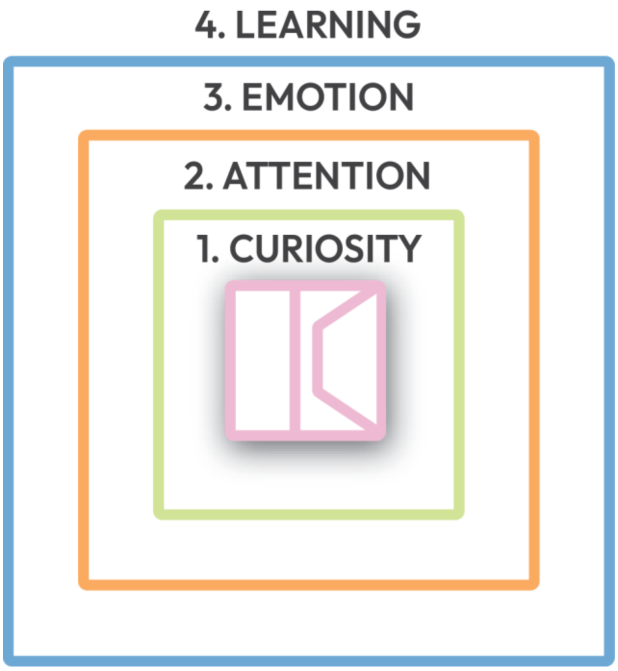


Fig 10. Proceso de aprendizaje según la Neuroeducación (Acaso & Megías, 2017)

<u>Trabajo en equipo como factor esencial</u>

El trabajo en equipo se considera una de las habilidades clave para acceder al mundo profesional (Daly et al., 2012; Tulsi & Poonia, 2015; Valero, 2018). Para su fomento, en todos los estudios presentados, el desarrollo de los proyectos por parte del alumnado fue en equipos. Concretamente, siempre que fue posible, se formaron equipos de tres o cuatro integrantes, que de acuerdo con Oakley et al. (2004) es el número óptimo de miembros; eran grupos manejables donde todos podían aportar sin subdivisiones de trabajo.

Las metodologías presentadas, al igual que otros enfoques como el Aprendizaje Basado en Proyectos, se dirigen hacia un modelo educativo basado en el aprendizaje por competencias; una de las docentes aseguró que "la metodología lleva a los alumnos a desarrollar competencias como el trabajo en equipo, el pensamiento crítico, el pensamiento divergente o la estructura mental". De hecho, el futuro personal docente (estudio 4 y 5) notó una contribución en la competencia de trabajo en equipo significativamente mayor en comparación con las otras contribuciones.

En este sentido, el tablero propuesto en el estudio 5 adaptó e incorporó el método de gestión de trabajo *Kanban*, de uso común en el desarrollo de software (Brechner, 2015), pero de especial interés en los entornos educativos (López-Alcarria et al., 2019; Parsons et al., 2018). La palabra japonesa *Kanban* significa tablero visual; específicamente, el tablero *Kanban* es una herramienta para mapear y visualizar el flujo de trabajo del proyecto. El tablero se divide en columnas para representar las etapas, por lo general: *To do, doing, done* (Schwaber & Sutherland, 2011); y las tareas se representan en tarjetas que avanzan a través de estas columnas de acuerdo con la progresión del trabajo. De acuerdo con estas bases y los resultados del estudio, el tablero basado en *Design Thinking* facilitó la participación e interacción en los equipos de futuro personal docente durante el proyecto, ya que permitió a cada participante ver el proceso de una manera muy visual y seguir el progreso del proyecto del principio a fin, apoyando el trabajo en equipo. Asimismo, mejoró y facilitó la labor y gestión de los proyectos a distancia por parte del profesorado responsable de la formación del futuro personal docente, de acuerdo con Noguera et al. (2018) y Uebe et al. (2019).

Divergencia además de convergencia

Con frecuencia, se valida únicamente una respuesta correcta y una única forma de conseguirla, sin más margen. Esta coyuntura implica que el alumnado tenga miedo al error y no piense de manera diferente, ya que la respuesta puede ser una mala calificación. Sin embargo, para desarrollar la capacidad de resolución de problemas, es importante que el profesorado tolere el error, y que el alumnado esté abierto a equivocarse y a buscar alternativas. El profesorado tiene aquí un papel importante como proveedor y director de recursos; en este sentido, las estrategias desarrolladas en los estudios les brindan la oportunidad de capacitar al alumnado en el manejo de materiales, herramientas, conceptos, ideas y estructuras, en línea con lo que Feldhusen y Treffinger (1985) y Gervilla (2003) reclaman.

Así, las estrategias presentadas en los estudios contribuyen a fomentar el pensamiento divergente del alumnado a partir de la incertidumbre, la asunción de riesgos y el error, en la línea de Craft (2003). Un ejemplo de ello son los métodos y técnicas incluidas propias del *Design Thinking* como la lluvia de ideas, en la que se incluyeron normas como, entre otras: evite el juicio y la crítica, construya sobre los pensamientos de los demás, aborde solo una conversación a la vez, anote todas las ideas, no hay ideas malas, o la importancia de usar bocetos simples.

En relación con esta última pauta, el estudio 6 incluyó talleres TSC para ayudar al alumnado a desbloquearse para comunicarse a través del boceto o *sketching*. Es importante señalar que, más del 90% del alumnado de ingeniería que participó en el estudio solo tenía formación técnica en dibujo. Esto implica que la mayoría indicase que lo que le resultó más difícil al comenzar a bocetar a mano alzada fue "no usar regla y compás". Se trata de estudiantes que parten del pensamiento convergente, utilizando el hemisferio izquierdo del cerebro para llegar a la solución; y necesitan desarrollar el pensamiento divergente, utilizando el cerebro derecho para fomentar la creatividad y generar muchas soluciones, conformándose como ingenieros de diseño, en línea con Blanco et al. (2017b).

En base a TSC, se establecieron clases de tres horas en sesiones compuestas por dos bloques: bloque de calentamiento y de experimentación, que incluían diferentes actividades para que el alumnado desconectase de la clase anterior, se sumergiera en la clase, conociese técnicas y consejos de dibujo, experimenta, ensuciase, etc. Esto fue percibido prácticamente por unanimidad como útil "me ha parecido ameno e interesante, sino es agotador y monótono", "me ha hecho comprender el objetivo de la asignatura y de las prácticas" (estudiantes). Las actividades de experimentación fueron las mejor valoradas; esto es comprensible porque el alumnado se relajó y experimentó abiertamente sin miedo al fracaso, bajo el lema de aprender haciendo y fallando (Bain, 2005). En base a los resultados y considerando que dibujar estimula el pensamiento creativo (Van der Lugt, 2005), TSC contribuyó a fomentar el pensamiento divergente, capacitando al alumnado para pensar creativamente.

La importancia de tiempos para la reflexión

Las estrategias desarrolladas brindan tiempos en los que el alumnado evalúa su progreso y desempeño, con el fin de promover la reflexión sobre lo aprendido. Estos tiempos están presentes durante el proceso de desarrollo del proyecto y al finalizar.

Un ejemplo de tiempos durante el proceso en el estudio 4 (TCT) son las actividades y retroalimentación para que el futuro personal docente reflexionase sobre la aplicación en el aula del material didáctico que estaba desarrollando. Concretamente, a través de la técnica de *Storyboard*, el futuro personal docente debía reflexionar bocetando ilustraciones simples sobre la secuencia de uso, considerando los tiempos necesarios, materiales complementarios, actividades, etc., con el objetivo de redefinir su material didáctico en base a ello.

Al finalizar el proyecto, en todas las metodologías propuestas se incluyen actividades para la autoevaluación. Por ejemplo, en el estudio 1 que aplica TCL con estudiantes de secundaria, al finalizar se les guio en la autoevaluación (su propio trabajo), coevaluación (el trabajo de su equipo) y heteroevaluación (a otro equipo) a través de dos estrellas (dos cuestiones favorables del trabajo realizado) y un deseo (una cuestión a mejorar).

Adicionalmente, el hecho de que el alumnado evaluase las estrategias desarrolladas en esta tesis durante su aplicación y al finalizar, les permitió reflexionar sobre la importancia del proceso que estaban realizando y les ayudó a la compresión profunda del mismo. De hecho, al inicio de todas las experimentaciones el alumnado vio el proceso como caótico, pero poco a poco fueron comprendiendo la estructura del proceso; lo cual es entendible, puesto que el diseño en sí mismo es multifacético y complejo (Brown & Wyatt, 2010; Dym et al., 2005; Razzouk & Shute, 2012; Teal, 2010) y la formación en diseño es un desafío (Henriksen et al., 2017).

En esta línea, tras la utilización de cada una de las metodologías propuestas se cuestionó a los participantes para que reflexionasen sobre la utilidad de la formación recibida para su futuro, y si les gustaría recibir más formación de este tipo durante sus años de formación. En la metodología TCL como en TCT, en las herramientas del tablero y de los talleres de TSC, las respuestas fueron positivas; tanto docentes como estudiantes consideraron útil esta formación, que impulsa el aprendizaje por competencias, fomenta la investigación, facilita el aprender haciendo y proporciona nuevas herramientas valiosas para su futuro, hacia la construcción de una sociedad sostenible.

<u>Transformación digital para acercar el aprendizaje</u>

En otro nivel, una sociedad sostenible requiere adoptar la transformación digital en la que estamos inmersos (Cerdá Suárez et al., 2021; Tejedor et al., 2021b). Es necesario renovar las metodologías aplicadas en el entorno educativo para adecuarlas en la era digital en la que nos encontramos; para ello, las nuevas tecnologías ofrecen multitud de posibilidades para crear y compartir ideas y contenidos (Henriksen et al., 2016; Lombardi, 2007). No obstante, es importante considerar premisas educativas para adaptarse a las necesidades pedagógicas (Tuhkala & Kärkkäinen, 2018).

Por ello, en el estudio 5 se presenta un tablero para materializar la metodología TCT en formato digital a través del software Trello, alcanzando resultados positivos. Gracias al conocimiento adquirido, se obtuvieron una serie de recomendaciones prácticas para el diseño y uso de este tipo de tableros. A continuación, se aporta una síntesis:

- Todo el espacio de trabajo debe estar cuidadosamente organizado para administrar proyectos de estudiantes con un software como Trello. A nivel del profesorado, es interesante empezar creando un espacio de trabajo con el nombre de la asignatura, que recopile todos los tableros correspondientes a los equipos de estudiantes de una misma asignatura. De esta forma, si el profesorado utiliza el software Trello en varias asignaturas, tiene un espacio de trabajo para cada una de ellas (Figura 11a).
- Cada uno de estos tableros debe tener un nombre que identifique al grupo de estudiantes; esto ayuda a que el profesorado identifique los grupos y el alumnado se consolide como equipo. Para organizar el tablero, Trello permite crear columnas para agregar tarjetas; en el estudio 5, todo el material de TCT se colocó organizado en la columna *to do*, con el objetivo de que el alumnado desarrolle su autonomía y pueda manejar las tareas en curso, las que están trabajando (*doing*) y las que han completado (*done*), sin que el profesorado intervenga en este proceso (Figura 11b).
- Transformar el material de la asignatura en un software como Trello no consiste en cargar un documento .pdf para que el alumnado lo lea. Es necesario crear un proceso en el que el material y Trello estén conectados y se complementen entre sí.
- Asimismo, es fundamental considerar la flexibilidad; el material debe estar conectado y dividido en tarjetas manejables, flexibles y fácilmente movibles. Así, la flexibilidad del material desarrollado debe hacerlo adaptable a las características de cada proyecto, ya que cada trabajo es diferente, y no todos los equipos de estudiantes hacen lo mismo o toman las mismas decisiones durante un proyecto.

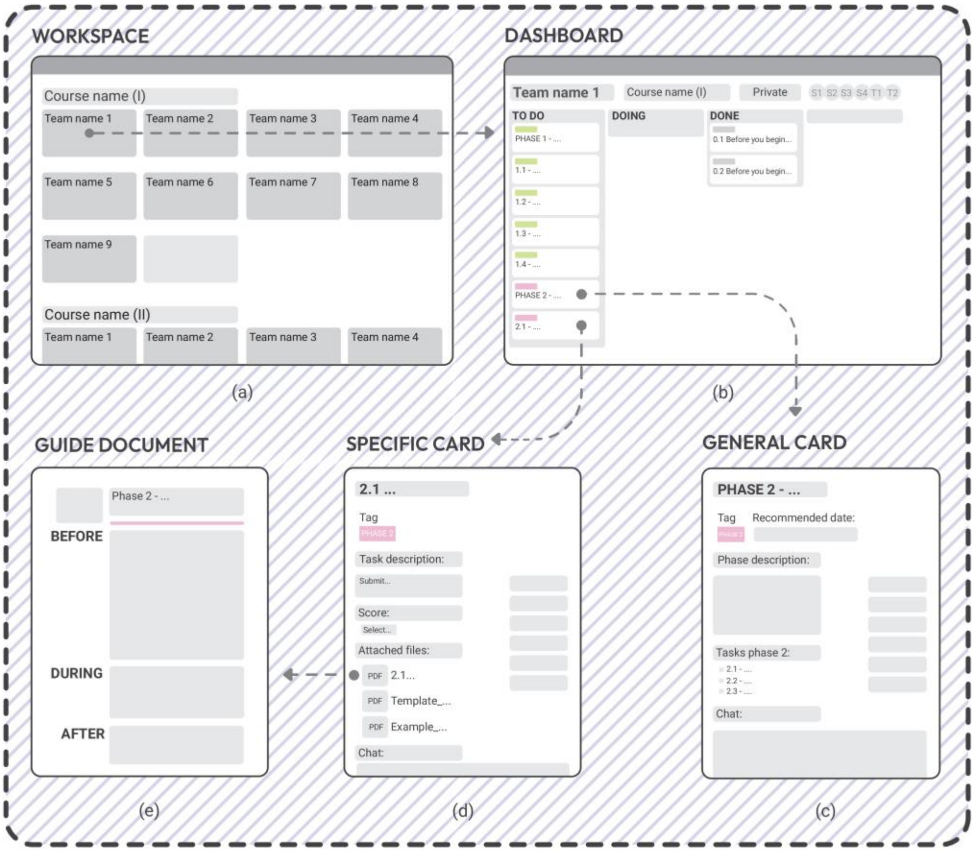


Fig 11. Organización y contenido de Trello (a) espacio de trabajo; (b) tablero; (c) tarjeta general; (d) tarjeta específica; documento guía (e).

- Es útil tener dos tipos de tarjetas. Por un lado, las tarjetas generales (Figura 11c) que tienen como objetivo introducir la fase, las tareas a realizar y una fecha aconsejable para su finalización. Por otro lado, las tarjetas específicas (Figura 11d) que tienen como objetivo guiar al alumnado en el proceso.
- Atributos recomendados para incluir en estas tarjetas: (1) establecer etiquetas de colores para ayudar al alumnado a visualizar las etapas del proyecto. (2) Un título conciso precedido por un número de acuerdo con la cronología numérica. Si bien, como se mencionó anteriormente, el proceso debe ser flexible, esta enumeración ayuda al alumnado a ubicarse y seguir el proceso de manera menos caótica. (3) Una descripción concreta de la tarea a realizar. (4) Un chat en el que el alumnado pregunte y el profesorado les de *feedback* adaptado a la situación concreta de cada equipo. Se recomienda que el profesorado agregue un comentario inicial en la tarjeta para crear un clima de confianza, por ejemplo, "¡Hola! Si tienes alguna pregunta, contáctanos". (5) Documentos adjuntos que guíen al estudiante durante el proyecto.
- Estos documentos guía deben conectarse y complementarse con las tarjetas para formar un solo material, es decir, el alumnado debe entender el tablero y los materiales como uno solo. Para ello, a nivel visual, estos documentos guía deben utilizar el mismo nombre, número, color y estética (Ejemplo Figura 11e). Además, a nivel estructural, es importante que estos documentos guía mantengan una organización simple, clara y conectada con el tablero. Una estructura de "antes", "durante" y "después" es óptima para desarrollar dichos

proyectos, y la mejor manera de proporcionar información es a través de consejos. Cuando el alumnado comienza a leer el documento guía, la sección “antes” les presenta dónde están y les brinda consejos para prepararse la tarea. La sección “durante” les da recomendaciones e indicaciones sobre cómo llevarla a cabo. Finalmente, la sección “después” explica cómo procesar y analizar la información recopilada.

- Al inicio del proyecto es importante contextualizar al alumnado que no está formado en metodologías activas como *Design Thinking* con una introducción visual y conectada a los intereses de su realidad. Asimismo, para la explicación del software, se debe crear previamente el tablero de cada equipo e invitar a cada miembro del equipo a unirse. De esta forma, todos los participantes seguirán paso a paso la sesión de formación. Durante la sesión, es recomendable partir de la visualización general hacia las especificaciones más concretas. Asimismo, es fundamental destacar que el tablero proporcionado es una herramienta flexible en la que cada equipo puede, por ejemplo: crear nuevas columnas y tarjetas, retroceder entre fases, cambiar el orden de las tarjetas, establecer fechas específicas en las tarjetas para la planificación, así como establecer qué integrantes van a realizar cada tarea. En definitiva, transmitir que el tablero no está cerrado, sino que se puede adaptar al proyecto de su equipo.
- Las metodologías como el *Design Thinking* promueven el trabajo en equipo, y aunque el panel es colaborativo, no permite crear sesiones grupales en línea. Así, el profesorado debe establecer sesiones programadas utilizando aplicaciones como Google Meet. Asimismo, es interesante que cada equipo tenga su propio “lienzo virtual” para trabajar a través de plantillas y notas adhesivas virtuales. La Figura 12 detalla un ejemplo de TCT creado a partir de una presentación de Google Drive. En este ejemplo, la plantilla creada se coloca como un fondo fijo y se agrega una pila de rectángulos, simulando notas adhesivas. De esta manera, las personas del equipo discuten a través de Meets y comparte la información de forma colaborativa; los cambios ocurren en tiempo real y son visibles para todas las personas. Este método de trabajo es beneficioso para la realización de talleres a distancia guiados por el profesorado.

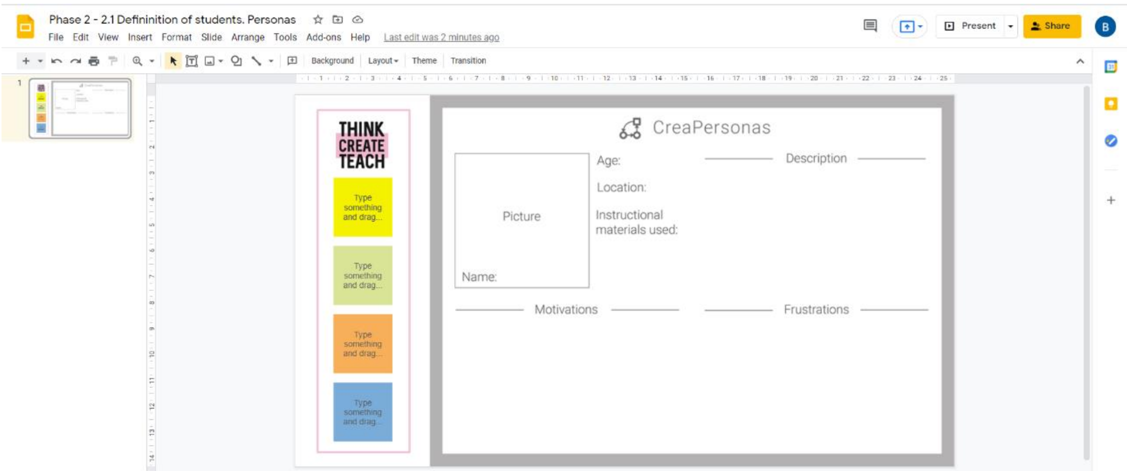


Fig 12. Ejemplo de lienzo virtual para trabajo en equipo.

- Además, es fundamental destacar algunas observaciones que pueden ayudar a suavizar las interacciones docente-estudiante durante el desarrollo del proyecto: (1) Establecer un clima cómodo para que el alumnado haga preguntas y participe. (2) Supervisar los tableros y brindar retroalimentación respondiendo preguntas y haciendo comentarios generales de seguimiento. Para facilitar esta tarea se recomienda agregar una columna de “espera” en el tablero para que el alumnado agregue las tarjetas con preguntas. (3) Hacer entender al alumnado que el seguimiento no es para espiarles sino para apoyarles, y que deben controlar su dependencia al apoyo.
- La gestión de proyectos con un tablero de este tipo proporciona datos para evaluar. En primer lugar, el profesorado realiza un seguimiento activo del alumnado durante el desarrollo del proyecto. El profesorado puede visualizar el trabajo de cada equipo, consultar las fechas de entrega, saber qué grupos están trabajando de manera continuada y cuáles al final, detectar los cambios de cada tablero en tiempo real, visualizar las dudas de los grupos al momento, dar *feedback* adaptado a cada grupo, conocer las tareas realizadas correctamente, incorrectamente o no realizadas, así como los resultados del proyecto. Además, esta información se recopila en el tablero para ayudar al profesorado a revisarla nuevamente.
- Se recomienda evaluar cada proyecto individualmente para considerar todo el proceso (los temas planteados, las decisiones tomadas, o el contexto de cada equipo). De esta forma, tanto alumnado como profesorado valoran la importancia del proceso, la evaluación continua y el aprendizaje constructivista, más que solo el resultado final.
- En segundo lugar, estos datos permiten al profesorado visualizar y autoevaluar sus propios materiales mediante diferentes indicadores. Por ejemplo, el profesorado puede ver qué tareas han sido las más complejas y si sus comentarios tuvieron un efecto positivo. Asimismo, es recomendable añadir una pestaña de “puntuación” en cada tarjeta (Figura 10d), que permita a cada equipo de estudiantes puntuar la tarjeta al final de la tarea, para que luego el profesorado pueda analizar qué tarjetas han sido más y menos útiles.

Estas *guidelines* pretenden describir la experiencia y los hallazgos de valor práctico de la aplicación del *Design Thinking*. Sin embargo, la generalización no es el enfoque y dichas pautas no son únicas ni estrictas. Estas *guidelines* pueden servir al personal educador y/o investigador para desarrollar soluciones prácticas y sostenibles.

4.4. Limitaciones y trabajo futuro

En esta sección se presentan las limitaciones de las investigaciones llevadas a cabo, así como las posibles líneas de trabajo futuro que pueden derivarse de esta tesis.

- En primer lugar, el alcance de los estudios se limita a muestras particulares, y los resultados pueden no ser completamente generalizables a otros contextos. No obstante, las nuevas estrategias desarrolladas se han aplicado en una muestra amplia de docentes y estudiantes de Enseñanzas universitarias y ESO, llegando a alcanzar Bachillerato, Educación Primaria y Educación Infantil, a través de los trabajos realizados por el alumnado. Así, el trabajo futuro podría explorar nuevas aplicaciones y evaluaciones de las metodologías propuestas en otros contextos. Cada nueva aplicación es una nueva oportunidad para incluir mejoras en las metodologías en función de las necesidades identificadas. Esto es clave, ya que las metodologías presentadas no están cerradas; su diseño es iterativo y están en continua mejora. De hecho, en el estudio 5, se observa como los resultados durante la segunda iteración fueron más favorables que en la primera; en parte, por este proceso de diseño iterativo llevado a cabo por el equipo x-disciplinar.

- En segundo lugar, cabe señalar que, una gran parte de las técnicas de investigación utilizadas en los estudios son cualitativas. En este tipo de investigación, los participantes confían en su experiencia, recuerdos y expectativas individuales, lo que impide que el estudio alcance la objetividad total, la neutralidad completa y sesga, en cierta medida, la investigación (Ponterotto, 2005). No obstante, para minimizar este efecto y dar mayor credibilidad, se evalúa cada objetivo de evaluación de cada estudio con diferentes métodos, combinando técnicas cuantitativas y cualitativas. De hecho, en evaluaciones con personas usuarias reales y entornos reales (como es el caso de los estudios presentados), los enfoques de métodos mixtos son clave para ayudar a interpretar y comprender los razonamientos (Blanco, 2016).

- En tercer lugar, a pesar de que las nuevas estrategias se adapten al currículo, aplicarlas requiere un esfuerzo por parte del profesorado, ya que debe actuar como entrenador, proveedor de recursos y diseñador, afrontando desafíos complejos y variados y enfrentándose a una situación desconocida. Por tanto, aunque las estrategias están planteadas para ser aplicadas en el entorno educativo, es preferible que el profesorado esté familiarizado con las nuevas metodologías y el *Design Thinking* o debe formarse en algunas de estas áreas. Para afrontar esta circunstancia, incluimos en el estudio 4 la formación al futuro personal docente, así como la incorporación de facilitadores capacitados en *Design Thinkig.*

- En cuarto lugar, del mismo modo, son metodologías exigentes para el alumnado, ya que debe estar plenamente activos. Además, a nivel general, el alumnado de las muestras analizadas estaba acostumbrado a la metodología tradicional. Por tanto, la carga de trabajo del alumnado debe estar bien equilibrada, ya que una sobrecarga podría ser perjudicial para su aprendizaje y su percepción de las metodologías activas. En este sentido, para enriquecer la experiencia y el aprendizaje, se podrían realizar investigaciones más profundas y ambiciosas, con sesiones más largas.

- En quinto lugar, cabe señalar que, entender y desarrollar conceptos sobre el *Design Thinking* y la creatividad no es sencillo, ya que son desordenados, multifacéticos y complejos. Así, entender y desarrollar el diseño y la creatividad no puede resolverse únicamente con el uso puntual de las metodologías propuestas, sino que se pueden considerar como una ayuda para introducir estos conceptos. Como línea general de trabajo futuro, es necesario que la formación del profesorado y la investigación educativa profundicen en apoyar al profesorado con nuevas herramientas y enfoques desde el *Design Thinking.*

- En sexto lugar, esta tesis se vio afectada por la situación de COVID-19, lo que condicionó notablemente la investigación (materiales, experimentaciones, resultados, etc.), especialmente a los posibles desarrollos TIC. No obstante, el COVID-19 supuso una oportunidad para abordar las TIC desde el punto de vista del aprendizaje remoto, hacia nuevos modelos de enseñanza y aprendizaje más centrados en el estudiante. Así, el estudio 5 muestra cómo adaptar las metodologías al formato digital. En este sentido, el *Design Thinking* ha sido el grueso de esta investigación, y las TIC una herramienta clave para su consecución, ofreciendo multitud de oportunidades que necesitan ser exploradas como trabajo futuro.

  Entre ellas, como trabajo futuro próximo, destacamos la planificación y desarrollo de un curso MOOC denominado "*Think-Create-Teach* (TCT). Una herramienta basada en el *Design Thinking* para que el profesorado trabaje el pensamiento lateral y desarrolle soluciones para su aula". Este curso MOOC pretende difundir y acercar la metodología de TCT desarrollada en la tesis (estudio 4 y 5) entre el profesorado, siendo "usuarios palanca" para llegar a la sociedad. Así, con este curso se busca mejorar las oportunidades educativas y el aprendizaje permanente, y se dirige a docentes con sensibilidad y motivación por el tema. Para su desarrollo e implementación se ha redactado una memoria del proyecto que incluye el objetivo, la justificación de su necesidad, el público objetivo, impacto, cronograma, organigrama, recursos necesarios, plan de contingencia y comunicación, y presupuesto, entre otros. Esta memoria ha sido enviada a la Convocatoria de Ayudas para el Fomento de la Cultura Científica, Tecnológica y de la Innovación (FECYT).

  Asimismo, para potenciar la línea de tecnología se ha planteado el posible desarrollo de *Think-Create-Play* (TCP), un dispositivo interactivo cuyo objetivo es que el alumnado trabaje el pensamiento divergente y fomente su creatividad. Para ello, TCP se basa en el juego con final abierto (open-ended game); se trata de que el alumnado juegue y experimente con un dispositivo interactivo que no tiene reglas, siendo ellos mismos los que crean sus propios juegos, buscando múltiples soluciones.

5. Investigación relacionada

El desarrollo de esta tesis ha dado lugar a otras acciones de investigación relacionadas que han favorecido y servido de soporte para profundizar en el progreso de esta. Fruto de las acciones llevadas a cabo se han llevado a cabo publicaciones científicas complementarios (5.1).

5.1. Contribuciones científicas relacionadas

Adicionalmente a las actividades de investigación expuestas en los capítulos previos, cabe destacar ciertos proyectos y acciones que se relacionan directamente con la temática de la tesis y ayudan a contextualizarla. En el Anexo I se describen los hitos clave desarrollados relacionados con la temática de la tesis.

Como resultado de las acciones relacionadas llevadas a cabo, se han difundido contribuciones científicas complementarias, que han sido la base para construir los estudios presentados en esta tesis:

- **Trabajo 7:** Calavia, M.B., Blanco, T., Casas, R. (2018). *Aportaciones desde el diseño y la tecnología para el fomento de la creatividad en entornos educativos* [Póster]. V Jornadas Doctorales de Campus Iberus, Jaca, España.
- **Trabajo 8:** Calavia, M.B., Blanco, T., Casas, R. (2018). *Analizando el desarrollo de la creatividad en entornos educativos: Una herramienta metodológica basada en el diseño* [Póster]. VII Jornada de Jóvenes Investigadores, del Instituto de Investigación en Ingeniería de Aragón (I3A), Zaragoza, España.
- **Trabajo 9:** Ferrández, M. B. C., Bascuas, T. B., & Nebra, R. C. (2018). Analizando el desarrollo de la creatividad en entornos educativos. Una herramienta metodológica basada en el diseño. *Jornada de Jóvenes Investigadores del Instituto de Investigación en Ingeniería de Aragón (I3A), 6.* https://doi.org/10.26754/jji-i3a.201802841
- **Trabajo 10:** Calavia, M.B., Blanco, T., Casas, R. (2018). *Diseño y tecnología para la creatividad como resolución de problemas. Evaluando una herramienta desde la x-disciplinaridad* [Presentación]. Congreso Internacional de Arte, Patrimonio y tecnología en la Era Digital, Zaragoza, España.
- **Trabajo 11:** Blanco, T., Calavia, M.B., Albero, E., Rivero, C., López-Baeza, E. (2019). *Design Thinking for Urban Water Resources Management* [Póster]. EU Water Innovation Conference 2020, Zaragoza, España.
- **Trabajo 12:** Calavia, M.B. (2018). *Aportaciones desde el diseño y la tecnología para el fomento de la creatividad en entornos educativos* [Presentación]. Seminario de Investigación en Departamento de Ingeniería de Diseño y Fabricación de la Universidad de Zaragoza, Zaragoza, España.
- **Trabajo 13:** Calavia, M. B., Blanco, T., Dieste, B. M., & Casas, R. (2020). Formando en Diseño a Futuros Maestros con una Herramienta Digital: "Think-Create-Teach". In *Edunovatic 2020. Conference Proceedings: 5th Virtual International Conference on Education, Innovation and ICT* (pp. 214-215). REDINE (Red de Investigación e Innovación Educativa).
- **Trabajo 14:** Calavia, M. B., Casas, R., Blanco, T., Dieste, B. M. (2020). Design Thinking como Herramienta Docente para Fomentar Competencias Transversales en Enseñanzas Tecnológicas. In *Edunovatic 2020. Conference Proceedings: 5th Virtual International Conference on Education, Innovation and ICT* (pp. 216-217). REDINE (Red de Investigación e Innovación Educativa).

- **Trabajo 15:** Calavia, M.B., Blanco, T., Dieste, B., Casas, R. (2021). *Herramienta para gestionar proyectos de diseño en la formación a distancia (COVID-19) de futuros maestros* [Presentación]. 54 Encuentro de Centros Innovadores, Logroño, España.
- **Trabajo 16:** Blanco, T., Calavia, M.B., Casas, R. (2021). *Think-Create-Learn y Think-Create-Teach: dos herramientas para el fomento de la creatividad en Educación Infantil y Primaria* [Presentación]. III Jornada de Reflexión sobre los Procesos de Coordinación Docente: una oportunidad para integrar los objetivos de desarrollo sostenible en el ámbito universitario, Zaragoza, España.
- **Trabajo 17:** Blasco, A., Aiger, M., Arranz, P., Blanco, T., Bravo, M., Calavia, M.B., Casasús, G., Cascarosa, E., Cid, Esperanza., Rodríguez, C., Val, S. (2022). Evaluación auténtica de competencias en la formación inicial del profesorado de secundaria. *XX Congreso Internacional de Investigación Educativa: Educación Inclusiva y Equitativa de Calidad*.

6. Conclusiones

6.1. Conclusiones de la investigación

Las conclusiones y aprendizajes de esta investigación responden a los objetivos propuestos en la introducción a lo largo de seis estudios de investigación en los siguientes términos:

El objetivo transversal de avanzar en nuevas estrategias para fomentar competencias transversales como la creatividad se ha cumplido con dos nuevas estrategias metodológicas basadas en *Design Thinking*: *Think-Create-Learn* (TCL), *Think-Create-Teach* (TCT); y con dos herramientas de aprendizaje basadas en las Tecnologías de la Información y la Comunicación (TIC) y *sketching* respectivamente: *DT-based board* y *Think-Sketch-Create* (TSC).

Para abordar con éxito el desarrollo e inclusión de estas propuestas resulta de utilidad establecer un equipo x-disciplinar de especialistas en diseño, tecnología y educación que trabajen conjuntamente bajo un entendimiento común.

Para facilitar este trabajo conjunto entre disciplinas es beneficioso aplicar un proceso basado en la metodología de *Design Thinking* compuesto por: (1) la fase de investigación y revisión de la literatura; (2) la fase de entendimiento y definición de necesidades; (3) la fase de diseño y desarrollo de nuevas estrategias para cubrir las necesidades detectadas en la literatura, y (4) la fase de aplicación y puesta en práctica de las estrategias desarrolladas con estudiantes y docentes para su evaluación y validación a partir de métodos mixtos.

En relación con el objetivo 1, como marco teórico y eje vertebrador del proceso, esta tesis contribuye con 15 factores a considerar en el diseño, desarrollo y validación de nuevas estrategias que fomenten la creatividad como resolución de problemas (estudio 1): incorporación al currículo, practicidad, novedad, clima, estimulación, análisis, cooperación, motivación intrínseca, participación, flexibilidad, incertidumbre, tiempo de reflexión, divergencia, autoevaluación y redefinición.

- En relación con el objetivo 2, el propósito de analizar el potencial del diseño y del *Design Thinking* en la formación del alumnado, se ha evidenciado con TCL (estudios 1-3), una nueva estrategia metodológica para ayudar al profesorado a promover competencias transversales como la creatividad en el alumnado.

  TCL se materializa en un kit práctico compuesto por un manual de 22 tarjetas guía que explica al profesorado paso a paso cómo aplicar TCL en el aula; así como plantillas complementarias para facilitar la aplicación, ofreciendo herramientas lo suficientemente flexibles para adaptarse a diferentes temas o asignaturas y ayudando al profesorado a gestionar la incertidumbre.

  Los resultados de su evaluación validan que TCL contempla los 15 factores clave para potenciar la creatividad como resolución de problemas en el alumnado, hacia la construcción de una sociedad sostenible. En definitiva, TCL contribuye a reafirmar el potencial de aplicar el *Design Thinking* para formar al alumnado, y aporta una solución ante la necesidad de nuevas estrategias para ayudar al profesorado a fomentar el modelo educativo basado en el aprendizaje por competencias.

- El objetivo 3 de analizar el potencial del diseño y del *Design Thinking* en la formación al futuro personal docente se ha evidenciado con TCT (estudio 4), una nueva estrategia metodológica para capacitar al futuro personal docente en *Design Thinking* con la finalidad de que sean capaces de identificar sus propias necesidades y diseñar sus propios materiales didácticos para abordarlas.

  TCT se materializa en un manual práctico de 15 tarjetas guía con plantillas, que ayuda al futuro personal docente a aplicar el proceso de *Design Thinking* desde una perspectiva completa que les permite dar un paso atrás y conectar sus conocimientos aprendidos.

  Los resultados de la evaluación demuestran la validez de TCT para la formación del futuro personal docente en diseño; les ayuda a entender la importancia del proceso y a diseñar materiales más adecuados, utilizables y creativos. En definitiva, esta formación permite al futuro personal docente trabajar sus propias competencias transversales, aplicar la disciplina del diseño con su futuro alumnado y abordar los complejos desafíos de su futura labor docente, como la creación de materiales didácticos.

  Así, la metodología de TCT contribuye a reafirmar el papel relevante que tiene la disciplina del diseño en la formación del futuro personal docente y la necesidad de crear nuevas soluciones prácticas para aplicar e integrar en esta formación. La investigación en esta dirección contribuye a propiciar el concepto de docentes como diseñadores.

- El propósito de analizar el potencial de la tecnología y las TIC en el aprendizaje, objetivo 4, ha quedado evidenciado con el tablero desarrollado *DT-based board* (estudio 5), que se basa en *Design Thinking* y mejora la implementación y gestión de proyectos de diseño en aprendizaje remoto con grandes grupos de estudiantes.

  Este tablero se construye a partir de premisas educativas sobre un proceso replicable y flexible en el que el material desarrollado se conecta y complementa con software existente (Trello). Este enfoque proporciona una organización visual y flexible, que permite que el desarrollo y la gestión de proyectos de diseño sean accesibles; incluso sin grandes conocimientos en diseño, gestión de proyectos o tecnología, como es el caso del futuro personal docente.

  Los resultados de la evaluación demuestran que el tablero permite tener una visión general del proyecto desde el principio, seguir el proceso de *Design Thinking* de forma remota, comprender la importancia del proceso, diseñar centrándose en el ser humano, y desarrollar competencias transversales hacia la sostenibilidad. Asimismo, el tablero facilita la gestión, supervisión y dirección adaptativa de los proyectos de manera remota; lo cual resulta especialmente útil para situaciones de aprendizaje remoto como la pandemia de COVID-19.

Este enfoque contribuye a la integración natural del *Design Thinking* y de las TIC en la formación del futuro personal docente, lo cual es clave para mejorar la calidad de la educación de las generaciones futuras.

- En respuesta al objetivo 5, el propósito de analizar el potencial de la expresión a través del boceto como lenguaje ha quedado evidenciado con TSC (estudio 6), una herramienta para ayudar al alumnado a desbloquearse para que sea capaz de expresar sus pensamientos e ideas a través del boceto. TSC se materializa en talleres prácticos, en los que el alumnado experimenta, pensando y reflexionando sobre el proceso y no sólo sobre el resultado final.

  Los resultados de la evaluación evidencian la validez de TSC; ayuda al alumnado a experimentar abiertamente, pensar en el proceso, aprender técnicas, entender que no deben lograr acabados hiperrealistas y trabajar el pensamiento divergente, capacitando al alumnado para pensar creativamente.

  Así, los talleres TSC ayudan a los futuros profesionales a desbloquearse para utilizar el boceto como medio de comunicación. En consecuencia, este estudio contribuye a reflejar el potencial del fomento de las habilidades de dibujo y la necesidad de desarrollar acciones para su formación continua como medio de comunicación en equipos de trabajo.

Estas estrategias están en continua mejora y su diseño es iterativo. Explorar nuevas aplicaciones y evaluaciones de las estrategias en otros contextos es clave para incluir mejoras en función de las necesidades identificadas. Con todo ello, la investigación aquí recogida y sus líneas futuras avanzan en ayudar al profesorado a responder a la educación cambiante de hoy, mejorando su calidad para las generaciones futuras hacia una sociedad sostenible.

Referencias

Acaso, M., & Megías. C. (2017). *Art thinking.* Ediciones Paidós.

Achtenhagen, F. (2001). Criteria for the development of complex teaching-learning environments. *Instructional Science, 29*(4-5), 361-380.

Admiraal, W., Louws, M., Lockhorst, D., Paas, T., Buynsters, M., Cviko, A., . . . Post, L. (2017). Teachers in school-based technology innovations: A typology of their beliefs on teaching and technology. *Computers & Education, 114*, 57-68.

Ahmadi, N., Peter, L., Lubart, T., & Besançon, M. (2019). School environments: Friend or foe for creativity education and research? In C.A. Mullen (Ed.), *Creativity under duress in education?* (pp. 255-266). Springer.

Alam, A. (2020). Challenges and possibilities of online education during covid-19. *Preprints, 1*(6), 1-4.

Ali, W. (2020). Online and remote learning in higher education institutes: A necessity in light of COVID-19 pandemic. *Higher Education Studies, 10*(3), 16-25.

Amabile, T. M. (1998). *How to kill creativity.* Harvard Business School Publishing.

Ashmann, S., & Franzen, R. L. (2017). In what ways are teacher candidates being prepared to teach about the environment? A case study from wisconsin. *Environmental Education Research, 23*(3), 299-323.

Bain, K. (2005). *Lo que hacen los mejores profesores universitarios.* Universitat de València.

Baranova, S., Nīmante, D., Kalniņa, D., & Oļesika, A. (2021). Students' perspective on remote on-line teaching and learning at the university of latvia in the first and second COVID-19 period. *Sustainability, 13*(21), 11890.

Baylor, A. L., & Ritchie, D. (2002). What factors facilitate teacher skill, teacher morale, and perceived student learning in technology-using classrooms? *Computers & Education, 39*(4), 395-414.

Bennett, S., Agostinho, S., & Lockyer, L. (2017). The process of designing for learning: Understanding university teachers' design work. *Educational Technology Research and Development, 65*(1), 125-145.

Bers, M. U., González-González, C., & Armas-Torres, M. B. (2019). Coding as a playground: Promoting positive learning experiences in childhood classrooms. *Computers & Education, 138*, 130-145.

Bilbao-Osorio, B., Dutta, S., & Lanvin, B. (2013). The global information technology report 2013. In *World Economic Forum* (pp.1-383). Geneva, Switzerland.

Blanco, T. (2016). *Metodologías de diseño como plataforma para la x-disciplinaridad en proyectos tecnológicos: Surfing disciplines* (Doctoral dissertation, Universitat Politècnic de València, Valencia, España). Retrieved from: https://riunet.upv.es/handle/10251/77149?show=full

Blanco, T., Berbegal, A., Blasco, R., & Casas, R. (2016). Xassess: Crossdisciplinary framework in user-centred design of assistive products. *Journal of Engineering Design, 27*(9), 636-664.

Blanco, T., Casas, R., Manchado-Pérez, E., Asensio, Á, & López-Pérez, J. M. (2017a). From the islands of knowledge to a shared understanding: Interdisciplinarity and technology literacy for innovation in smart electronic product design. *International Journal of Technology and Design Education, 27*(2), 329-362.

Blanco, T., López-Forniés, I., & Zarazaga-Soria, F. J. (2017b). Deconstructing the tower of babel: A design method to improve empathy and teamwork competences of informatics students. *International Journal of Technology and Design Education, 27*(2), 307-328.

Blasco-Serrano, A. C., González, I. B., & Coma-Roselló, T. (2022). Incorporación de las TIC en la formación inicial del profesorado mediante Flipped Classroom para potenciar la educación inclusiva. *Edutec. Revista Electrónica De Tecnología Educativa*, (79), 9-29.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3-4), 369-398.

Booth, J. W., Taborda, E. A., Ramani, K., & Reid, T. (2016). Interventions for teaching sketching skills and reducing inhibition for novice engineering designers. *Design Studies, 43*, 1-23.

Brechner, E. (2015). *Agile project management with kanban*. Pearson Education.

Brown, T. (2008). Design thinking. *Harvard Business Review, 86*(6), 84.

Brown, T., & Wyatt, J. (2010). Design thinking for social innovation. *Development Outreach, 12*(1), 29-43.

Brundiers, K., Barth, M., Cebrián, G., Cohen, M., Diaz, L., Doucette-Remington, S., . . . Jarchow, M. (2021). Key competencies in sustainability in higher education—toward an agreed-upon reference framework. *Sustainability Science, 16*(1), 13-29.

Buhl, A., Schmidt-Keilich, M., Muster, V., Blazejewski, S., Schrader, U., Harrach, C., . . . Süßbauer, E. (2019). Design thinking for sustainability: Why and how design thinking can foster sustainability-oriented innovation development. *Journal of Cleaner Production, 231*, 1248-1257.

Bullen, M., & Morgan, T. (2016). Digital learners not digital natives. *La Cuestión Universitaria,* (7), 60-68.

Burgos, E. R. (2020). El proceso de enseñanza y aprendizaje ante el tránsito de la docencia presencial a la docencia virtual universitaria provocada por la covid. In *Edunovatic 2020. Conference Proceedings: 5th Virtual International Conference on Education, Innovation and ICT* (pp. 132-135). REDINE (Red de Investigación e Innovación Educativa).

Burkus, D. (2013). *The myths of creativity: The truth about how innovative companies and people generate great ideas.* John Wiley & Sons.

Burnard, P. (2006). Reflecting on the creativity agenda in education. *Cambridge Journal of Education, 36*(3), 313-318.

Caniglia, G., John, B., Kohler, M., Bellina, L., Wiek, A., Rojas, C., . . . Lang, D. (2016). An experience-based learning framework: Activities for the initial development of sustainability competencies. *International Journal of Sustainability in Higher Education,* 827-852.

Carrión-Martínez, J. J., Luque-de la Rosa, A., Fernandez-Cerero, J., & Montenegro-Rueda, M. (2020). Information and communications technologies (ICTs) in education for sustainable development: A bibliographic review. *Sustainability, 12*(8), 3288.

Carroll, M. (2014). Shoot for the moon! the mentors and the middle schoolers explore the intersection of design thinking and STEM. *Journal of Pre-College Engineering Education Research (J-PEER), 4*(1), 3.

Carroll, M., Goldman, S., Britos, L., Koh, J., Royalty, A., & Hornstein, M. (2010). Destination, imagination and the fires within: Design thinking in a middle school classroom. *International Journal of Art & Design Education, 29*(1), 37-53.

Caruso, C. (2011). *The Tools of Engagement: Bridging Design Thinking and Social Media to Enhance and Support Collaborative Learning* (Doctoral dissertation, Carleton University, Ottawa, Ontario).

Carvalho, A., Areal, N., & Silva, J. (2011). Students' perceptions of blackboard and moodle in a portuguese university. *British Journal of Educational Technology, 42*(5), 824-841.

Castellaro, M., & Peralta, N. S. (2020). Pensar el conocimiento escolar desde el socioconstructivismo: Interacción, construcción y contexto. *Perfiles Educativos, 42*(168), 140-156.

Cerdá Suárez, L. M., Núñez-Valdés, K., & Quirós y Alpera, S. (2021). A systemic perspective for understanding digital transformation in higher education: Overview and subregional context in latin america as evidence. *Sustainability, 13*(23), 12956.

Chan, S., & Yuen, M. (2014). Personal and environmental factors affecting teachersâ€™ creativity-fostering practices in hong kong. *Thinking Skills and Creativity, 12*, 69-77.

Chang, L., & Lee, G. C. (2010). A team-teaching model for practicing project-based learning in high school: Collaboration between computer and subject teachers. *Computers & Education, 55*(3), 961-969.

Clarke, M. (2018). Rethinking graduate employability: The role of capital, individual attributes and context. *Studies in Higher Education, 43*(11), 1923-1937.

Colás-Bravo, P., Conde-Jiménez, J., & Reyes-de-Cózar, S. (2021). Sustainability and digital teaching competence in higher education. *Sustainability, 13*(22), 12354.

Coleman, M. C. (2016). Design thinking and the school library. *Knowledge Quest, 44*(5), 62-68.

Collaguazo, A., Villavicencio, M., & Abran, A. (2020). Education model for developing IoT and cloud mobile applications. In *2020 IEEE World Congress on Services (SERVICES)* (pp. 251-258). Beijing, China.

Collard, P., & Looney, J. (2014). Nurturing creativity in education. *European Journal of Education, 49*(3), 348-364.

Craft, A. (2002). *Creativity in the early years: A lifewide foundation.* A&C Black.

Craft, A. (2003). The limits to creativity in education: Dilemmas for the educator. *British Journal of Educational Studies, 51*(2), 113-127.

Cropley, A. (2016). The myths of heaven-sent creativity: Toward a perhaps less democratic but more down-to-earth understanding. *Creativity Research Journal, 28*(3), 238-246.

Cropley, A. (2018). The creativity-facilitating teacher index: Early thinking, and some recent reflections. In K. Soh (Ed.), *Creativity Fostering Teacher Behavior: Measurement and Research* (pp. 1-15). Singapore: World Scientific.

Cross, N. (2011). *Design thinking: Understanding how designers think and work.* Berg.

Dag, F., & Durdu, L. (2017). Pre-service teachers' experiences and views on project-based learning processes. *International Education Studies, 10*(7), 18-39.

Daly, S. R., Adams, R. S., & Bodner, G. M. (2012). What does it mean to design? A qualitative investigation of design professionals' experiences. *Journal of Engineering Education, 101*(2), 187-219.

Daly, S. R., Mosyjowski, E. A., & Seifert, C. M. (2014). Teaching creativity in engineering courses. *Journal of Engineering Education, 103*(3), 417-449.

Davies, D., Jindal-Snape, D., Collier, C., Digby, R., Hay, P., & Howe, A. (2013). Creative learning environments in education. A systematic literature review. *Thinking Skills and Creativity, 8*, 80-91.

De Bono, E., & Castillo, O. (1994). *El pensamiento creativo.* Editorial Paidós.

De Prada, E., Mareque, M., & Pino-Juste, M. (2022). Teamwork skills in higher education: Is university training contributing to their mastery? *Psicologia: Reflexão E Crítica, 35*(1), 1-13.

De Vries, H. B., & Lubart, T. I. (2019). Scientific creativity: Divergent and convergent thinking and the impact of culture. *The Journal of Creative Behavior, 53*(2), 145-155.

Design Council. (2021). *Design methods for developing services*. Retrieved from https://www.designcouncil.org.uk/our-work/skills-learning/the-double-diamond/

Dickhut, J. E. (2003). *A brief review of creativity.* Retrieved from: *http://www.personalityresearch.org/papers/dickhut.html*

Dorst, K. (2010). The nature of design thinking. In *Design Thinking Research Symposium,* (pp. 131-139). DAB Documents.

Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problem-solution. *Design Studies, 22*(5), 425-437.

Duran, M., & Dökme, I. (2016). The effect of the inquiry-based learning approach on student's critical-thinking skills. *Eurasia Journal of Mathematics Science and Technology Education, 12*(12).

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103-120.

Edtech. (2022). *The european edtech funding report 2022*. Retrieved from https://www.brighteyevc.com/post/the-european-edtech-funding-report-2022

Eissen, K., & Steur, R. (2012). *Sketching: Basics.* Stiebner Verlag GmbH.

Elwood, K., Savenye, W., Jordan, M. E., Larson, J., & Zapata, C. (2016). Design thinking: A new construct for educators. In *the Annual Convention of the Association of Educational Communicatios and Technology* (pp. 17-21). Las Vegas, NV.

Erbas, A. K., & Bas, S. (2015). The contribution of personality traits, motivation, academic risk-taking and metacognition to the creative ability in mathematics. *Creativity Research Journal, 27*(4), 299-307.

Fasko, D. (2001). Education and creativity. *Creativity Research Journal, 13*(3-4), 317-327.

Feldhusen, J. F., & Treffinger, D. J. (1985). *Creative thinking and problem solving in gifted education.* Kendall/Hunt Publishing Company.

Fernandes, J. M., van Hattum-Janssen, N., Ribeiro, A. N., Fonte, V., Santos, L. P., & Sousa, P. (2012). An integrated approach to develop professional and technical skills for informatics engineering students. *European Journal of Engineering Education, 37*(2), 167-177.

Fien, J. (1995). Teaching for a sustainable world: The environmental and development education project for teacher education. *Environmental Education Research, 1*(1), 21-33.

Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative cognition: Theory, research, and applications.* MIT press.

Freeman, A., Becker, S. A., & Cummins, M. (2017). *NMC/CoSN Horizon Report: 2017 K.* The New Media Consortium.

Gallardo-Echenique, E. E., Marqués-Molías, L., Bullen, M., & Strijbos, J. (2015). Let's talk about digital learners in the digital era. *The International Review of Research in Open and Distributed Learning, 16*(3)

Gatwood, J., Hohmeier, K., Kocak, M., & Chisholm-Burns, M. (2021). Acceptance of productivity software as a course management and collaboration tool among student pharmacists. *Currents in Pharmacy Teaching and Learning, 13*(4), 361-367.

Geisinger, K. F. (2016). 21st century skills: What are they and how do we assess them? *Applied Measurement in Education, 29*(4), 245-249.

Gerver, R. (2017). Crear hoy la escuela del mañana: El futuro de la educación. In *I International Congress of Educational Innovation.* Zaragoza, Spain.

Gervilla, A. (2003). *Creatividad aplicada. Una Apuesta De Futuro.* Málaga: Editorial Dykinson.

Gibson, P. A., Stringer, K., Cotten, S. R., Simoni, Z., O'neal, L. J., & Howell-Moroney, M. (2014). Changing teachers, changing students? the impact of a teacher-focused intervention on students' computer usage, attitudes, and anxiety. *Computers & Education, 71*, 165-174.

Gisbert, M., & Esteve, F. (2016). Digital leaners: La competencia digital de los estudiantes universitarios. *La Cuestión Universitaria,* (7), 48-59.

Gleason, B., & Cherrez, N. J. (2021). Design thinking approach to global collaboration and empowered learning: Virtual exchange as innovation in a teacher education course. *TechTrends,* , 1-11.

Goddard, Y. L., Goddard, R. D., & Tschannen-Moran, M. (2007). A theoretical and empirical investigation of teacher collaboration for school improvement and student achievement in public elementary schools. *Teachers College Record, 109*(4), 877-896.

Goldman, S., & Zielezinski, M. B. (2016). Teaching with design thinking: Developing new vision and approaches to twenty-first century learning. In L.A. Annetta, J. Minogue (Eds.), *Connecting science and engineering education practices in meaningful ways* (pp. 237-262). Springer, Cham

Gómez, O. Y. A. (2018). Las TIC como herramientas cognitivas. *Revista Interamericana De Investigación, Educación Y Pedagogía, 11*(1), 67-80.

González, C. A. (2006). Evaluación de la creatividad. más allá de una operatoria funcional. In *Comprender y evaluar la creatividad* (pp.625-636). Aljibe.

Goto, S., Ishida, S., Gemba, K., & Yaegashi, K. (2014). The interaction between design research and technological research in manufacturing firm. In *Smart manufacturing innovation and transformation: Interconnection and intelligence,* (pp. 226-251). IGI Global.

Grammenos, D., & Antona, M. (2018). Future designers: Introducing creativity, design thinking & design to children. *International Journal of Child-Computer Interaction, 16*, 16-24.

Gryaditskaya, Y., Sypesteyn, M., Hoftijzer, J. W., Pont, S. C., Durand, F., & Bousseau, A. (2019). OpenSketch: A richly-annotated dataset of product design sketches. *ACM Trans.Graph., 38*(6), 232-1.

Gu, X., Dijksterhuis, A., & Ritter, S. M. (2019). Fostering childrenâ€™s creative thinking skills with the 5-I training program. *Thinking Skills and Creativity, 32*, 92-101.

Guilford, J. P. (1967a). Creativity: Yesterday, today and tomorrow. *The Journal of Creative Behavior, 1*(1), 3-14.

Guilford, J. P. (1950b). Creativity. *American Psychologist, 5*(9), 444-454.

Guilford, J. P. (1967). *The nature of human intelligence.* McGraw-Hill.

Guillén-Gámez, F. D., Higueras-Rodríguez, L., & Medina-García, M. (2020). Developing a regression model of cooperative learning methodology in pre-service teacher education: A sustainable path for transition to teaching profession. *Sustainability, 12*(6), 2215.

Guo, J., & Woulfin, S. (2016). Twenty-first century creativity: An investigation of how the partnership for 21st century instructional framework reflects the principles of creativity. *Roeper Review, 38*(3), 153-161.

Hadar, L. L., & Tirosh, M. (2019). Creative thinking in mathematics curriculum: An analytic framework. *Thinking Skills and Creativity, 33*, 100585.

Häkkinen, P., Järvelä, S., Mäkitalo-Siegl, K., Ahonen, A., Näykki, P., & Valtonen, T. (2017). Preparing teacher-students for twenty-first-century learning practices (PREP 21): A framework for enhancing collaborative problem-solving and strategic learning skills. *Teachers and Teaching, 23*(1), 25-41.

Havazík, O., & Pavlíčková, P. (2020). How to design agile game for education purposes in JIRA. In *2020 7th International Conference on Control, Decision and Information Technologies (CoDIT)* (331-334). IEEE.

Hennessey, B., & Amabile, T. (1987). *Creativity and learning*. Washington, DC: NEA Professional Library.

Henriksen, D., Mishra, P., & Fisser, P. (2016). Infusing creativity and technology in 21st century education: A systemic view for change. *Educational Technology & Society, 19*(3), 27-37.

Henriksen, D., Richardson, C., & Mehta, R. (2017). Design thinking: A creative approach to educational problems of practice. *Thinking Skills and Creativity, 26*, 140-153.

Hensley, N. (2018). Transforming higher education through trickster-style teaching. *Journal of Cleaner Production, 194*, 607-612.

Hernández-Leo, D., Agostinho, S., Beardsley, M., Bennet, S., & Lockyer, L. (2017). Helping teachers to think about their design problem: A pilot study to stimulate design thinking. In *9th International Conference on Education and New Learning Technologies* (pp. 5681-90). Barcelona, Spain.

Hernández-Torrano, D., & Ibrayeva, L. (2020). Creativity and education: A bibliometric mapping of the research literature (1975-2019). *Thinking Skills and Creativity, 35*, 100625.

Hilton, E. C., Paige, M., Williford, B., Li, W., Hammond, T., & Linsey, J. (2017). Improving the sketching ability of engineering design students. In *21st International Conference on Engineering Design (ICED 17)* (pp. 217-224). Vancouver, Canada.

Hoogveld, A. W., Paas, F., & Jochems, W. M. (2005). Training higher education teachers for instructional design of competency-based education: Product-oriented versus process-oriented worked examples. *Teaching and Teacher Education, 21*(3), 287-297.

Howard, T. J., Culley, S. J., & Dekoninck, E. (2008). Describing the creative design process by the integration of engineering design and cognitive psychology literature. *Design Studies, 29*(2), 160-180.

Huidobro, T., & González, J. (2004). *Una definición de la creatividad a través del estudio de 24 autores seleccionados.* Universidad Complutense de Madrid.

Ibáñez, R. M. (1998). *La creatividad: Diagnóstico, evaluación e investigación.* Uned.

IDEO. (2015). The field guide to human-centered design: Design kit. Retrieved from https://www.ideo.com/post/design-kit

Jang, S. (2009). Exploration of secondary students' creativity by integrating web-based technology into an innovative science curriculum. *Computers & Education, 52*(1), 247-255.

Jenkins, H., Purushotma, R., Weigel, M., Clinton, K., & Robison, A. J. (2009). *Confronting the challenges of participatory culture: Media education for the 21st century*. Mit Press.

Jenny, P. (2013). *Técnicas de dibujo.* Gustavo Gili.

Jonassen, D. H. (1994). Thinking technology: Toward a constructivist design model. *Educational Technology, 34*(4), 34-37.

Jonassen, D. H. (2000). *Computers as mindtools for schools: Engaging critical thinking.* Prentice hall.

Jordan, M. E. (2016). Teaching as designing: Preparing pre-service teachers for adaptive teaching. *Theory into Practice, 55*(3), 197-206.

Kalantzis, M., & Cope, B. (2020). After the COVID-19 crisis: Why higher education may (and perhaps should) never be the same. *Educational Philosophy and Theory, 40*(1), 51-55.

Kali, Y., McKenney, S., & Sagy, O. (2015). Teachers as designers of technology enhanced learning. *Instructional Science, 43*(2), 173-179.

Kali, Y., & Ronen-Fuhrmann, T. (2011). Teaching to design educational technologies. *International Journal of Learning Technology, 6*(1), 4-23.

Kerr, S. T. (1981). How teachers design their materials: Implications for instructional design. *Instructional Science, 10*(4), 363-378.

Khalid, M., Saad, S., Hamid, S. R. A., Abdullah, M. R., Ibrahim, H., & Shahrill, M. (2020). Enhancing creativity and problem solving skills through creative problem solving in teaching mathematics. *Creativity Studies, 13*(2), 270-291.

Kirschner, P. A. (2015). Do we need teachers as designers of technology enhanced learning? *Instructional Science, 43*(2), 309-322.

Kleiman, P. (2008). Towards transformation: Conceptions of creativity in higher education. *Innovations in Education and Teaching International, 45*(3), 209-217.

Kleon, A. (2016). *Aprende a promocionar tu trabajo: 10 recursos para artistas, diseñadores y creativos.* Gustavo Gili.

Koehler, M. J., & Mishra, P. (2005). Teachers learning technology by design. *Journal of Computing in Teacher Education, 21*(3), 94-102.

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools, 19*(3), 267-277.

Kraleva, R., Sabani, M., & Kralev, V. (2019). An analysis of some learning management systems. *International Journal on Advanced Science, Engineering and Information Technology, 9*(4), 1190-1198.

Laurillard, D. (2013). *Teaching as a design science: Building pedagogical patterns for learning and technology.* Routledge.

Lee, M., & Erdogan, I. (2007). The effect of science–technology–society teaching on students' attitudes toward science and certain aspects of creativity. *International Journal of Science Education, 29*(11), 1315-1327.

Lewin, C., & McNicol, S. (2015). Supporting the development of 21st century skills through ICT. In T.Brinda, N. Reynolds, R. Romeike, & A. Schwill (Eds.), *KEYCIT 2014- Key Competencies in Informatics and ICT,* (pp. 98-181). University Press: Potsdam, Germany.

Lewis, T. (2009). Creativity in technology education: Providing children with glimpses of their inventive potential. *International Journal of Technology and Design Education, 19*(3), 255-268.

Lin, L., Shadiev, R., Hwang, W., & Shen, S. (2020). From knowledge and skills to digital works: An application of design thinking in the information technology course. *Thinking Skills and Creativity,* , 100646.

Lindberg, T., Meinel, C., & Wagner, R. (2011). Design thinking: A fruitful concept for it development? In *Design thinking* (pp. 3-18). Springer.

Lindberg, T., Noweski, C., & Meinel, C. (2010). Evolving discourses on design thinking: How design cognition inspires meta-disciplinary creative collaboration. *Technoetic Arts: A Journal of Speculative Research, 8*(1)

Lingard, R., & Barkataki, S. (2011). Teaching teamwork in engineering and computer science. In *2011 Frontiers in Education Conference (FIE)* (pp. F1C-1-F1C-5). IEEE.

Llorente, V. (2021). *¿Cuándo dejamos de dibujar?* Círculo Sophia. Retrieved from https://www.sophiaonline.com.ar/cuando-dejamos-de-dibujar/

Lodico, M. G., Spaulding, D. T., & Voegtle, K. H. (2010). *Methods in educational research: From theory to practice.* John Wiley & Sons.

Logan, L. M., Logan, V. G., & García, A. R. (1980). *Estrategias para una enseñanza creativa.* Oikos-tau.

Lombardi, M. M. (2007). Authentic learning for the 21st century: An overview. *Educause Learning Initiative, 1*(2007), 1-12.

LOMLOE (2020). Ley Orgánica 3/2020, de 29 de diciembre, por la que se modifica la Ley Orgánica 2/2006, de 3 de mayo, de Educación. *Boletín Oficial del Estado, 340*, de 30 de diciembre de 2020, 122868-122953. Retrieved from: https://www.boe.es/eli/es/lo/2020/12/29/3

López, O. (2008). Enseñar creatividad: El espacio educativo. *Cuadernos De La Facultad De Humanidades Y Ciencias Sociales.Universidad Nacional De Jujuy,* (35), 61-75.

López-Alcarria, A., Olivares-Vicente, A., & Poza-Vilches, F. (2019). A systematic review of the use of agile methodologies in education to foster sustainability competencies. *Sustainability, 11*(10), 2915.

Lor, R. (2017). Design thinking in education: A critical review of literature. In *International Academic Conference on Social Sciences and Management* (pp. 36-68). Bangkok, Thailand.

Luka, I. (2014). Design thinking in pedagogy. *The Journal of Education, Culture, and Society,* (2), 63-74.

MacLaren, I. (2012). The contradictions of policy and practice: Creativity in higher education. *London Review of Education, 10*(2), 159-172.

Marín, J., Blanco, T., Marín, J. J., Moreno, A., Martitegui, E., & Aragüés, J. C. (2019). Integrating a gait analysis test in hospital rehabilitation: A service design approach. *PloS One, 14*(10), e0224409.

Martin, R., & Martin, R. L. (2009). *The design of business: Why design thinking is the next competitive advantage.* Harvard Business Press.

Martínez, M. C., Manzano, M. J. R., Lema, L. E. C., & Andrade, L. C. V. (2019). Formación por competencias: Reto de la educación superior. *Revista De Ciencias Sociales, 25*(1), 94-101.

McIntosh, E. (2012). *What's the difference between PBL and design thinking?* Retrieved from https://medium.com/notosh/whats-the-difference-between-pbl-and-design-thinking-32ea04c46116

McKenney, S., Kali, Y., Markauskaite, L., & Voogt, J. (2015). Teacher design knowledge for technology enhanced learning: An ecological framework for investigating assets and needs. *Instructional Science, 43*(2), 181-202.

McKilligan, S., Fila, N., Rover, D., & Mina, M. (2017). Design thinking as a catalyst for changing teaching and learning practices in engineering. In *2017 IEEE Frontiers in Education Conference (FIE),* (pp. 1-5). IEEE.

McMullan, M. J. (2016). How using technology enhanced learning could help modernise traditional large group teaching or lecturing. *International Journal of Innovative Research in Medical Science (IJIRMS)(Online),* 2245-8737.

Melles, G., Anderson, N., Barrett, T., & Thompson-Whiteside, S. (2015). Problem finding through design thinking in education. In *Inquiry-based learning for multidisciplinary programs: A conceptual and practical resource for educators* (pp. 191-209). Emerald Group Publishing Limited.

Merriam, S. B. (1988). *Case study research in education: A qualitative approach.* Jossey-Bass.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017-1054.

Mishra, P., & Mehta, R. (2017). What we educators get wrong about 21st-century learning: Results of a survey. *Journal of Digital Learning in Teacher Education, 33*(1), 6-19.

Moore, T., & Morton, J. (2017). The myth of job readiness? written communication, employability, and the 'skills gap'in higher education. *Studies in Higher Education, 42*(3), 591-609.

Morgan, H. (2020). Best practices for implementing remote learning during a pandemic. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas, 93*(3), 135-141.

Mosely, G., Wright, N., & Wrigley, C. (2018). Facilitating design thinking: A comparison of design expertise. *Thinking Skills and Creativity, 27*, 177-189.

Mourlam, D. J., Strouse, G. A., Newland, L. A., & Lin, H. (2019). Can they do it? A comparison of teacher candidates' beliefs and preschoolers' actual skills with digital technology and media. *Computers & Education, 129*, 82-91.

Moya, E. C. (2017). Using active methodologies: The StudentśView. *Procedia-Social and Behavioral Sciences, 237*, 672-677.

Naghshbandi, S. (2020). Exploring the impact of experiencing design thinking on teachers' conceptualizations and practices. *TechTrends, 64*, 868-877.

Nakano, T. d. C., & Wechsler, S. M. (2018). Creativity and innovation: Skills for the 21st century. *Estudos De Psicologia (Campinas), 35*(3), 237-246.

Nguyen, K. A., DeMonbrun, R. M., Borrego, M. J., Prince, M. J., Husman, J., Finelli, C. J., . . . Waters, C. (2017). The variation of nontraditional teaching methods across 17 undergraduate engineering classrooms. In *2017 American Society of Engineering Education Annual Meeting* (pp. 1-13). Columbus, Ohio.

Noguera, I., Guerrero-Roldán, A., & Masó, R. (2018). Collaborative agile learning in online environments: Strategies for improving team regulation and project management. *Computers & Education, 116*, 110-129.

Norp, B., & Van Hoek, E. (2019). Industrial design sketching in practice. In *21st International Conference on Engineering and Product Design Education (E&PDE)* (pp. 1-10).

Norton, P., & Hathaway, D. (2015). In search of a teacher education curriculum: Appropriating a design lens to solve problems of practice. *Educational Technology,* , 3-14.

Nousheen, A., Zai, S. A. Y., Waseem, M., & Khan, S. A. (2020). Education for sustainable development (ESD): Effects of sustainability education on pre-service teachers' attitude towards sustainable development (SD). *Journal of Cleaner Production, 250*, 119537.

Oakley, B., Felder, R., Brent, R., & Elhajj, I. (2004). Coping with hitchhikers and couch potatoes on teams. *Journal of Student Centered Learning, 2*(1), 32-34.

Pande, M., & Bharathi, S. V. (2020). Theoretical foundations of design thinking–A constructivism learning approach to design thinking. *Thinking Skills and Creativity, 36*, 100637.

Parsons, D., Thorn, R., Inkila, M., & MacCallum, K. (2018). Using trello to support agile and lean learning with scrum and kanban in teacher professional development. In *2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)* (pp.720-724). IEEE.

Patton, M. Q. (2014). *Qualitative research & evaluation methods: Integrating theory and practice.* Sage publications.

Pérez, J. M., & Tejedor, S. (2016). *Ideas para aprender a aprender: Manual de innovación educativa y tecnología.* Editorial UOC.

Peterson, R. E. (2001). Establishing the creative environment in technology education: Creativity doesn't just happen by chance; the prepared environment nourished it. *The Technology Teacher, 61*(4), 7-11.

Phillips, A., Edwards, S., Parmesar, K., Soltan, M., & Guckian, J. (2021). Slack as a virtual undergraduate dermatology community: A pilot study. *Clinical and Experimental Dermatology, 46*(6), 1028-1037.

Ponterotto, J. G. (2005). Qualitative research training in counseling psychology: A survey of directors of training. *Teaching of Psychology, 32,* 60-62.

Qi, J. (2017). An optimization approach for flipped classroom and multimedia teaching innovation by contrast with traditional teaching. *Boletín Técnico, 55*(8), 480-488.

Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important? *Review of Educational Research, 82*(3), 330-348.

Retna, K. S. (2016). Thinking about "design thinking": A study of teacher experiences. *Asia Pacific Journal of Education, 36*(sup1), 5-19.

Riebe, L., Roepen, D., Santarelli, B., & Marchioro, G. (2010). Teamwork: Effectively teaching an employability skill. *Education Training, 52*(62-67), 528-539.

Rysavy, M. D., & Michalak, R. (2020). Working from home: How we managed our team remotely with technology. *Journal of Library Administration, 60*(5), 532-542.

Saini, C., & Abraham, J. (2019). Implementing facebook-based instructional approach in pre-service teacher education: An empirical investigation. *Computers & Education, 128*, 243-255.

Salas-Rueda, R., Castañeda-Martínez, R., Eslava-Cervantes, A., & Alvarado-Zamorano, C. (2022). Teachers' perception about MOOCs and ICT during the COVID-19 pandemic. *Contemporary Educational Technology, 14*(1), ep343.

Sánchez-Cruzado, C., Santiago, R., & Sánchez-Compaña, M. (2021). Teacher digital literacy: The indisputable challenge after COVID-19. *Sustainability, 13*(4), 1858.

Sancho-Gil, J. M., & Hernández-Hernández, F. (2018). La profesión docente en la era del exceso de información y la falta de sentido. *Revista De Educación a Distancia (RED),* (56).

Scheer, A., Noweski, C., & Meinel, C. (2012). Transforming constructivist learning into action: Design thinking in education. *Design and Technology Education: An International Journal, 17*(3).

Schmid, R. F., Bernard, R. M., Borokhovski, E., Tamim, R. M., Abrami, P. C., Surkes, M. A., . . . Woods, J. (2014). The effects of technology use in postsecondary education: A meta-analysis of classroom applications. *Computers & Education, 72*, 271-291.

Schwaber, K., & Sutherland, J. (2011). The scrum guide. *Scrum Alliance, 21*(19), 1.

Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2017). Learning by making. In K. Peppler (Ed.), *The SAGE encyclopedia of out-of-school learning* (pp. 421–424). Thousand Oaks, California: SAGE.

Seltzer, K., & Bentley, T. (1999). *The creative age: Knowledge and skills for the new economy*. Demos.

Şendağ, S., & Odabaşı, H. F. (2009). Effects of an online problem based learning course on content knowledge acquisition and critical thinking skills. *Computers & Education, 53*(1), 132-141.

Şendurur, E., Ersoy, E., & Çetin, İ. (2016). The design and development of creative instructional materials: The role of domain familiarity for creative solutions. *International Journal of Technology and Design Education,* , 1-16.

Serrano, J. M., & Pons, R. M. (2011). El constructivismo hoy: Enfoques constructivistas en educación. *Revista Electrónica De Investigación Educativa, 13*(1), 1-27.

Shaheen, R. (2010). Creativity and education. *Online Submission, 1*(3), 166-169.

Sim, S. K., & Duffy, A. H. (2003). Towards an ontology of generic engineering design activities. *Research in Engineering Design, 14*(4), 200-223.

Simonton, D. K. (2000). Creativity: Cognitive, personal, developmental, and social aspects. *American Psychologist, 55*(1), 151.

Spendlove, D. (2008). Creativity in education: A review. *Design and Technology Education: An International Journal, 10*(2).

Stanford University Institute of Design. (2021). *Our point of view.* Retrieved from http://dschool.stanford.edu/our-point-of-view/#design-thinking

Starkey, L. (2019). Three dimensions of student-centred education: A framework for policy and practice. *Critical Studies in Education, 60*(3), 375-390.

Sternberg, R. J., & Lubart, T. I. (1997). *La creatividad en una cultura conformista: Un desafío a las masas.* Barcelona: Ediciones Paidós.

Stevenson, M., Bower, M., Falloon, G., Forbes, A., & Hatzigianni, M. (2019). By design: Professional learning ecologies to develop primary school teachers' makerspaces pedagogical capabilities. *British Journal of Educational Technology, 50*(3), 1260-1274.

Stokholm, M. (2014). Problem based learning versus design thinking in team based project work. In *DS 78: Proceedings of the 16th International Conference on Engineering and Product Design Education (E&PDE14), Design Education and Human Technology Relations* (pp. 268-274). University of Twente, the Netherlands.

Stolaki, A., & Economides, A. A. (2018). The creativity challenge game: An educational intervention for creativity enhancement with the integration of information and communication technologies (ICTs). *Computers & Education, 123*, 195-211.

Sund, L. (2016). Facing global sustainability issues: Teachers' experiences of their own practices in environmental and sustainability education. *Environmental Education Research, 22*(6), 788-805.

Teal, R. (2010). Developing a (non- linear) practice of design thinking. *International Journal of Art & Design Education, 29*(3), 294-302.

Tejedor, G., Sánchez-Carracedo, F., & Segalàs, J. (2022). Education for sustainable development in higher education-introduction to a special issue. *Sustainability, 14*(17), 10530.

Tejedor, S., Cervi, L., Pérez-Escoda, A., Tusa, F., & Parola, A. (2021a). Higher education response in the time of coronavirus: Perceptions of teachers and students, and open innovation. *Journal of Open Innovation: Technology, Market, and Complexity, 7*(1), 43.

Tejedor, S., Cervi, L., Tusa, F., & Parola, A. (2021b). University teachers face the change to virtual education imposed by the coronavirus. *Sociedade e Estado, 36*, 915-943.

Thapa, A., Cohen, J., Guffey, S., & Higgins-D'Alessandro, A. (2013). A review of school climate research. *Review of Educational Research, 83*(3), 357-385.

Thorsteinsson, G., & Page, T. (2017). Teaching creativity across the curriculum through design education. case studies. *Educatia 21,* (15), 13-22.

Toomey, E., Matthews, J., & Hurley, D. A. (2017). Using mixed methods to assess fidelity of delivery and its influencing factors in a complex self-management intervention for people with osteoarthritis and low back pain. *BMJ Open, 7*(8), e015452.

Torra, I., de Corral, I., Pérez, M. J., Valderrama, E., Márquez, M. D., Sabaté, S., . . . Guardia, L. (2012). Identificación de competencias docentes que orienten el desarrollo de planes de formación dirigidos a profesorado universitario. *REDU, Revista De Docencia Universitaria, 2012, Vol.10, Núm.2, P.21-56,*

Torrance, E. (1972). Can we teach children to think creatively? *The Journal of Creative Behavior, 6*(2), 114-143.

Torre, d. l. S., & Violant, V. (2006). *Comprender y evaluar la creatividad: cómo investigar y evaluar la creatividad.* Aljibe.

Tsybulsky, D., & Muchnik-Rozanov, Y. (2019). The development of student-teachers' professional identity while team-teaching science classes using a project-based learning approach: A multi-level analysis. *Teaching and Teacher Education, 79*, 48-59.

Tuhkala, A., & Kärkkäinen, T. (2018). Using slack for computer-mediated communication to support higher education students' peer interactions during master's thesis seminar. *Education and Information Technologies, 23*(6), 2379-2397.

Tulsi, P., & Poonia, M. (2015). Expectations of industry from technical graduates: Implications for curriculum and instructional processes. *Journal of Engineering Education Transformations,* , 19-24.

Uebe, A. F., Alves, A. C., & Torres, R. B. (2019). Trello as virtual learning environment and active learning organiser for PBL classes: An analysis under bloom's taxonomy. In *11th International Symposium on Project Approaches in Engineering Education and 16th Active Learning in Engineering Education Workshop* (pp. 1-8). Tunis, Tunisia.

UNESCO (2016). *Educación 2030. declaración de incheon y marco de acción para la realización del objetivo de desarrollo sostenible 4.* Retrieved from: https://unesdoc.unesco.org/ark:/48223/pf0000245656_spa

Valero, A. (2018). *Así es el aula que prepara para las habilidades del futuro, según bMaker.* Business Insider. Retrieved from: https://www.businessinsider.es/asi-es-aula-que-prepara-habilidades-futuro-segun-bmaker-329303

Van der Lugt, R. (2005). How sketching can affect the idea generation process in design group meetings. *Design Studies, 26*(2), 101-122.

Vass, E. (2017). Building dialogic spaces through inclusive conversations. *Engaging Schooling: Developing Exemplary Education for Students in Poverty,* 63.

Velázquez, R. V., Piguave, C. C., Valdés, I. E., & Zúñiga, K. M. (2020). Metodologías de enseñanza-aprendizaje constructivista aplicadas a la educación superior. *Revista Científica Sinapsis, 3*(18)

Verstijnen, I. M., van Leeuwen, C., Goldschmidt, G., Hamel, R., & Hennessey, J. (1998). Sketching and creative discovery. *Design Studies, 19*(4), 519-546.

Victorino, G., Bandeira, R., Painho, M., Henriques, R., & Coelho, P. S. (2022). Rethinking the campus experience in a post-COVID world: A multi-stakeholder design thinking experiment. *Sustainability, 14*(13), 7655.

Vigo, M. B., & Soriano, J. (2014). Prácticas de enseñanza y aprendizaje creativo para una educación inclusiva en la formación inicial del profesorado: Experiencias de investigación. *Revista De Educación Inclusiva, 7*(1), 30-45.

Voelkl, K. E. (1995). School warmth, student participation, and achievement. *The Journal of Experimental Education, 63*(2), 127-138.

Wilhelm, W. J., Logan, J., Smith, S. M., & Szul, L. F. (2002). *Meeting the demand: Teaching "soft" skills.* Delta Pi Epsilon Publishers.

Wilson, A. (2005). *Creativity in primary education: Theory and practice* (achieving QTS cross-curricular strand). Learning Matters Ltd.

Withell, A., Cochrane, T., Reay, S., Gaziulusoy, I., & Inder, S. (2012). Augmenting the design thinking studio. *In Proceedings of the Australian Society for Computers in Learning in Tertiary Education Annual Conference* (pp. 25-28). Wellington, New Zealand.

Wright, N., & Wrigley, C. (2017). Broadening design-led education horizons: Conceptual insights and future research directions. *International Journal of Technology and Design Education, 29*(1), 1-23.

Zhang, W., & Guo, A. (2017). Research on the blended teaching mode for computer network course. In *2017 4th International Conference on Social Science and Humanity* (pp. 45-49). Madrid, Spain.

Zhao, J., & Meng, Z. (2015). Information transfer technique in classroom interaction. *US-China Foreign Language 13 (5), 357-362.*

Zhu, T., & Ryzhkov, O. (2021). Application of agile methodology in planning a joint educational program. In *2021 IEEE International Conference on Smart Information Systems and Technologies (SIST)* (pp. 1-5). IEEE.

Anexos

En esta sección se incluyen proyectos y acciones de investigación relacionadas con la temática de tesis (Anexo I), así como las contribuciones de la doctoranda a cada una de las publicaciones (Anexo II), junto con el factor de impacto y la categoría de las revistas en las que se publicaron los estudios que conforman esta tesis (Anexo III).

Anexo I: Proyectos y acciones de investigación relacionadas

Adicionalmente a las actividades de investigación expuestas en los capítulos previos, cabe destacar ciertos proyectos y acciones que se relacionan directamente con la temática de la tesis y ayudan a contextualizarla. A continuación, se describen los hitos clave desarrollados relacionados con la temática de la tesis.

Proyectos innovación docente relacionados

En primer lugar, la colaboración con la Facultad de Educación y la formación del grupo de trabajo x-disciplinar ha supuesto la participación en nuevas propuestas para el Programa de Innovación Docente de la Universidad de Zaragoza desde el punto de vista planteado en la tesis. En concreto se ha participado en los proyectos de:

- "Diseño, implementación y análisis de un espacio de libre elección dirigido a estudiantes del Grado en Magisterio en Educación Infantil, docentes y niños y niñas de Educación Infantil" (código de proyecto PIIDUZ_1_9). Curso académico 2021-2022.
- "Diseño y desarrollo de Recursos Didácticos para el área de CC Naturales en Educación Infantil a través de la unión de metodologías de Design Thinking y Aprendizaje Servicio. Un proyecto interdisciplinar Universidad-Centros educativos-Centros Sociolaborales" (código de proyecto PIIDUZ_1_343). Curso académico 2021-2022.
- "Diseño participativo de un sistema de evaluación auténtica de las competencias docentes y profesionales en la formación inicial docente" (código de proyecto PIIDUZ_1_321). Curso académico 2021-2022.

Otros proyectos en colaboración relacionados

Adicionalmente, se ha participado en otros proyectos de investigación para aportar desde la perspectiva holística del campo del diseño y del *Design Thinking* en su sentido más amplio:

- Colaboración en un proyecto multidisciplinar del Proyecto de Innovación Estratégica de Titulación (PIET) "Siempre activODS: un pasaporte competencial para el alumnado de la Facultad de Educación. Hacia modelos de formación integral de los futuros maestros" denominado "Al abordaje. Aula Hospitalaria". La línea del proyecto se centra en el rediseño de aulas hospitalarias (espacios dentro de los centros hospitalarios para la continuidad del aprendizaje de los jóvenes hospitalizados) para el fomento del aprendizaje por competencias, en línea con la temática de tesis. Curso académico 2020-2021.

- Participación en El Programa Experimental "HIPATIA" para colaborar con el Centro Aragonés de Tecnologías para la Educación (CATEDU) Andressa Casamayor en la inclusión del *Design Thinking* en educación, en línea con la temática de tesis. Curso académico 2020-2021.

Formación impartida relacionada

Durante el desarrollo de esta tesis, se han impartido clases, talleres y *mentorías* a partir de las nuevas estrategias metodológicas desarrolladas, con la finalidad de validarlas y fomentar el pensamiento creativo y las competencias transversales de los participantes en los entornos educativos:

- Docencia como personal investigador en formación (PIF) en la asignatura de "Laboratorio de Diseño Electrónico" impartida durante el segundo cuatrimestre de cuarto curso, en el grado de Ingeniería de Tecnologías y Servicios de Telecomunicación (Universidad de Zaragoza). Aplicación de la metodología TCL (ver figura 5). Se obtuvo la calificación definitiva de "Positiva destacada", curso académico 2019-2020.
- Docencia como personal investigador en formación (PIF) en la asignatura de "Materiales y Recursos Didácticos" impartida durante el segundo cuatrimestre de segundo curso, en el grado de Magisterio de Educación Infantil (Universidad de Zaragoza). Aplicación de la metodología TCT (ver figura 5). Se obtuvo la calificación definitiva de "Positiva destacada", curso académico 2020-2021.
- Docencia como personal investigador en formación (PIF) en la asignatura de "La Educación en la Sociedad del Conocimiento" impartida durante el segundo cuatrimestre de segundo curso, en el grado de Magisterio de Educación Primaria (Universidad de Zaragoza). Aplicación de la metodología TCT (ver figura 5). Se obtuvo la calificación definitiva de "Positiva destacada", curso académico 2020-2021.
- Docencia como personal investigador en formación (PIF) en la asignatura de "Expresión Artística" impartida durante el primer cuatrimestre de primer curso, en el Grado de Ingeniería en Diseño Industrial y Desarrollo de Producto (Universidad de Zaragoza). Aplicación de la herramienta TSC (ver figura 5). Se obtuvo la calificación definitiva de "Positiva destacada", curso académico 2021-2022.
- Docencia como personal investigador en formación (PIF) en la asignatura de "Contenidos disciplinares de tecnología" impartida durante el segundo cuatrimestre del Máster Universitario en Profesorado de Educación Secundaria Obligatoria, Bachillerato, Formación Profesional y Enseñanzas de Idiomas, Artísticas y Deportivas (Universidad de Zaragoza). Aplicación de la metodología TCT (ver figura 5). Se obtuvo la calificación definitiva de "Positiva destacada", curso académico 2021-2022.
- Codirección de un Trabajo Fin de Grado (TFG) titulado "Diseño de una herramienta educativa de realidad aumentada, basada en la animación de elementos del patrimonio histórico-artístico" en el Grado de Ingeniería en

Diseño Industrial y Desarrollo de Producto (Universidad de Zaragoza), en línea con la temática de tesis. Curso académico 2021-2022.

- Mentoría en el Copernicus Climathon Burjassot 2018 (3 de septiembre en Valencia) *"Tackling Water Innovation Challenges. Role of Copernicus Earth Observation products. How can we optimise water resources management and use?"* junto con la Dra. Teresa Blanco Bascuas.
- Talleres de diseño (basados en la metodología de TCL) en el Copernicus Climathon Burjassot 2018 (3 de septiembre en Valencia) *"Tackling Water Innovation Challenges. Role of Copernicus Earth Observation products. How can we optimise water resources management and use?"* junto con la Dra. Teresa Blanco Bascuas.
- Mentoría en el Copernicus Climathon Burjassot 2019 (25 de octubre en Valencia) *"How can we make urban vegetation more effective?"* junto con la Dra. Teresa Blanco Bascuas.
- Talleres de diseño (basados en la metodología de TCL) en el Copernicus Climathon Burjassot 2019 (25 de octubre en Valencia) *"How can we make urban vegetation more effective?"* junto con la Dra. Teresa Blanco Bascuas.
- Talleres de trabajo en la Facultad de Educación de la Universidad de Zaragoza sobre diseño para la diversidad en educación junto con la Dra. Teresa Blanco Bascuas, en línea con la temática de tesis.

Formación recibida relacionada con la tesis

Asimismo, durante el desarrollo de esta tesis, se ha recibido formación continuada vinculada directamente al tema del proyecto de tesis y considerada de alto interés para el desarrollo de la misma.

- Realización de un curso de "Exaptación & diversidad, curso creativo para investigación y ciencia" (40 horas). Instituto Aragonés de Empleo.
- Realización de un curso de "Creatividad en las TIC. TIC para la creatividad" (9 horas). Fundación Ibercaja.
- Realización de un curso de "La publicación científica" (6 horas). Universidad de Zaragoza.
- Realización de un curso de "TIC + AULA INVERTIDA" (2 horas). Universidad de Zaragoza.
- Realización de un curso de "Introducción a la docencia universitaria" (12 horas). Universidad de Zaragoza.
- Realización de un curso de "Aspectos básicos de ADD/Moodle" (25 horas). Universidad de Zaragoza.
- Realización de un curso de "Trabajo en equipo: cómo fomentar esta competencia, organizarla y evaluarla" (6 horas). Universidad de Zaragoza.
- Realización de un taller de "Creatividad y Tecnopedagogía" (4 horas). Red de Educadores DIM-EDU.

- Realización de un curso de “Formación Pedagógica para el Profesorado Universitario Novel” (25 horas). Universidad de Zaragoza.
- Realización de un curso de “Taller: Cómo construir un perfil digital de investigador. Plan de trabajo” (8 horas). Universidad de Zaragoza.
- Realización de un taller de “Taller: Estrategias para incluir los Objetivos de Desarrollo Sostenible (ODS) en la docencia universitaria (edición presencial)” (3 horas). Universidad de Zaragoza.
- Realización de un curso de “Recursos TIC/TAC en el aula universitaria. Herramientas para el aprendizaje y consejos sobre su uso” (4 horas). Universidad de Zaragoza.
- Asistencia la Mesa Redonda de “Innovación y sostenibilidad en el sector Cultural” (3 horas) y participación en el taller de “Idear experiencias de ciencia ciudadana para exposiciones culturales” (3 horas). Universidad de Zaragoza.
- Asistencia y participación a los seminarios de “Innovación y Buenas Prácticas Docentes de la EINA” y a las sesiones de “Motivación y formación en los ODS” llevadas a cabo en la EINA.

Anexo II: Contribución a los artículos

A continuación, de acuerdo con las bases de la Escuela de Doctorado de la Universidad de Zaragoza, se especifican las tareas en las que ha contribuido la doctoranda en cada uno de los artículos realizados en coautoría.

Estudio 1: Calavia, M. B., Blanco, T., & Casas, R. (2021). Fostering creativity as a problem-solving competence through design: Think-Create-Learn, a tool for teachers. *Thinking skills and creativity, 39,* 100761.

https://doi.org/10.1016/j.tsc.2020.100761

- Conceptualización.
- Revisión de literatura.
- Metodología (diseño, desarrollo, aplicación, sesiones con especialistas, experimentación).
- Análisis de datos.
- Redacción del manuscrito.
- Maquetación y visualización.
- Adquisición de fondos.

Estudio 2: Calavia, M.B., Blanco, T., & Casas. R. (2019). Recursos basados en el diseño para fomentar la creatividad en el aula. In *V International Conference on Learning, Innovation and Competitiveness (CINAIC)* (pp. 590-595). Madrid, España.

http://dx.doi.org/10.26754/CINAIC.2019.0120

- Conceptualización.
- Revisión de literatura.
- Metodología (diseño, desarrollo, aplicación, sesiones con especialistas, experimentación).
- Análisis de datos.
- Redacción del manuscrito.
- Maquetación y visualización.
- Adquisición de fondos.

Estudio 3: Calavia, M.B., Blanco, T., & Casas. R. (2019). Formando a personas creativas en la era digital. Evaluación x-disciplinar de una herramienta basada en el diseño. In Foradada, C. & Irala-Hortal, P. (Eds.), *Re_Visiones sobre arte, patrimonio y tecnología en la era digital,* (pp. 185-184). Gobierno de Aragón.

ISBN: 978-84-8380-411-7

- Conceptualización.
- Revisión de literatura.
- Adaptación de la metodología.
- Redacción del manuscrito.
- Maquetación y visualización.
- Adquisición de fondos.

Estudio 4: Calavia, M. B., Blanco, T., Casas, R., & Dieste, B. (2022). Making Design Thinking for Education sustainable: Training preservice teachers to address practice challenges. *Thinking skills and creativity,* 101199.

https://doi.org/10.1016/j.tsc.2022.101199

- Conceptualización.
- Revisión de literatura.
- Metodología (diseño, desarrollo, aplicación, sesiones con especialistas, experimentación).
- Análisis de datos.
- Redacción del manuscrito.
- Maquetación y visualización.
- Adquisición de fondos.

Estudio 5: Calavia, M. B., Blanco, T., Casas, R., & Dieste, B. (2022). Improving Design Project Management in Remote Learning. *Sustainability, 14*(17), 11025.

https://doi.org/10.3390/su141711025

- Conceptualización.
- Revisión de literatura.
- Metodología (diseño, desarrollo, aplicación, sesiones con especialistas, experimentación).
- Análisis de datos.
- Redacción del manuscrito.
- Maquetación y visualización.
- Adquisición de fondos.

Estudio 6: Calavia, M. B., Blanco, T., Serrano, A., Biedermann, A., & Casas, R. (2022). Think-Sketch-Create: Improving Creative Expression Through Sketching. In Gerbino, S., Lanzotti, A., Martorelli, M., Mirálbes Buil, R., Rizzi, C., Roucoules, L. (Eds.), *Advances on Mechanics, Design Engineering and Manufacturing IV. JCM 2022. Lecture Notes in Mechanical Engineering* (pp. 1585-1597). Springer, Cham.

https://doi.org/10.1007/978-3-031-15928-2_138

- Conceptualización.
- Revisión de literatura.
- Metodología (diseño, desarrollo, aplicación, experimentación, sesiones con alumnos).
- Análisis de datos.
- Redacción del manuscrito.
- Maquetación y visualización.
- Adquisición de fondos.

Anexo III: Factor de impacto y categorías de las revistas

A continuación, se describe la Base de Datos (BD) en la que está indexada cada revista, el Factor de Impacto (FI) y las categorías y cuartiles (Q) ordenadas según conexión temática con la tesis. Estos datos corresponden al año de publicación, excepto en las publicadas en 2022 (estudios 4, 5 y 6), que se toma la información del último año disponible, 2021.

Estudio 1: Calavia, M. B., Blanco, T., & Casas, R. (2021). Fostering creativity as a problem-solving competence through design: Think-Create-Learn, a tool for teachers. *Thinking skills and creativity, 39,* 100761.

https://doi.org/10.1016/j.tsc.2020.100761

BD: JCR | FI: 3.652 | Q: *Education & Educational Research* (Q1 - 63/270)

BD: SJR | FI: 1.157 | Q: *Education* (Q1)

Estudio 2: Calavia, M.B., Blanco, T., & Casas. R. (2019). Recursos basados en el diseño para fomentar la creatividad en el aula. In *V International Conference on Learning, Innovation and Competitiveness (CINAIC)* (pp. 590-595). Madrid, España.

http://dx.doi.org/10.26754/CINAIC.2019.0120

BD: N/A

Estudio 3: Calavia, M.B., Blanco, T., & Casas. R. (2019). Formando a personas creativas en la era digital. Evaluación x-disciplinar de una herramienta basada en el diseño. In Foradada, C. & Irala-Hortal, P. (Eds.), *Re_Visiones sobre arte, patrimonio y tecnología en la era digital,* (pp. 185-184). Gobierno de Aragón.

ISBN: 978-84-8380-411-7

BD: N/A

Estudio 4: Calavia, M. B., Blanco, T., Casas, R., & Dieste, B. (2022). Making Design Thinking for Education sustainable: Training preservice teachers to address practice challenges. *Thinking skills and creativity,* 101199.

https://doi.org/10.1016/j.tsc.2022.101199

BD: JCR | FI: 3.652 | Q: *Education & Educational Research* (Q1 - 63/270)

BD: SJR | FI: 1.157 | Q: *Education* (Q1)

Estudio 5: Calavia, M. B., Blanco, T., Casas, R., & Dieste, B. (2022). Improving Design Project Management in Remote Learning. *Sustainability, 14*(17), 11025.

https://doi.org/10.3390/su141711025

BD: JCR | FI: 3.889 | Q: *Environmental Sciences* (Q2 - 133/279)

Q: *Environmental Studies* (Q2 - 57/128)

Q: *Green & Sustainable Science & Technology* (Q4 - 7/9)

Q: *Green & Sustainable Science & Technology* (Q3 - 35/47)

BD: SJR | FI: 0.664 | Q: *Energy Engineering and Power Technology* (Q2)

Q: *Environmental Science* (Q2)

Q: *Geography, Planning and Development* (Q1)

Q: *Management, Monitoring, Policy and Law* (Q2)

Q: *Renewable Energy, Sustainability and Environment* (Q2)

Estudio 6: Calavia, M. B., Blanco, T., Serrano, A., Biedermann, A., & Casas, R. (2022). Think-Sketch-Create: Improving Creative Expression Through Sketching. In Gerbino, S., Lanzotti, A., Martorelli, M., Mirálbes Buil, R., Rizzi, C., Roucoules, L. (Eds.), *Advances on Mechanics, Design Engineering and Manufacturing IV. JCM 2022. Lecture Notes in Mechanical Engineering* (pp. 1585-1597). Springer, Cham.

https://doi.org/10.1007/978-3-031-15928-2_138

BD: SJR | FI: 0.19 | Q: *Mechanical Engineering* (Q4)

Q: *Automotive Engineering* (Q4)

Q: *Aerospace Engineering* (Q4)

Q: *Fluid Flow and Transfer Processes* (Q4)

Universidad Zaragoza

1542