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# Developing a scale for design thinking mindset and abilities: Measuring the course impact among multidisciplinary undergraduate students

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## Abstract
Design Thinking (DT), the collaborative and human-centered problem-solving approach to tackling complex issues, is one of the most coveted skill sets of the twenty-first century. Institutions in industry and academia are actively seeking train- ing opportunities to increase their staff's capability to harness the intricacies of DT. However, although there have been several different methods and curric- ula aimed at increasing individuals' abilities in utilizing DT, previous studies do not put forth a validated scale that can be used to evaluate the impact of DT training on multidisciplinary undergraduate students with no prior DT experi- ence. We address this gap by providing a validated scale to measure the impact of DT mindsets and skills and to reveal the impact of a DT course based on self-reported quantitative data from 162 participants (control: 34, experimental: 128) who completed pre- and post-assessments. Moreover, we provide the result- ing two-factor structure, Flexible Thinking and Openness to Feedback, and show a statistically significant positive impact of a DT course for undergraduate stu- dents from diverse disciplines. In our experiment, modifying the IDEO Toolkit model by incorporating'video sketching' and a'cryptomnesia-preventing guerrilla thinking task' allowed us to develop a more affordable and universally accessible curriculum, as well as playing a crucial role in facilitating the development pro- cess. The validated scale developed in this research holds significant potential for adoption across educational, business, and industrial contexts, where fostering creativity and innovation is critical.

**Keywords** Design Thinking · Scale Development · Undergraduate multidisciplinary course · Design Thinking Impact Measurement · Design Thinking Mindset and Abilities

## Introduction

Design thinking (DT) is an approach that fosters collaboration and human-centered problem-solving to tackle complex, ill-defined issues, often referred to as"wicked problems" (Brown & Katz, 2019; Buchanan, 1992). By promoting a set of mindsets and

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abilities that enhance creative thinking (e.g., building empathy for user needs (X. Li et al., 2024), enhancing experiential intelligence, and accepting uncertainty and risk (Schweitzer et al., 2016), DT empowers individuals from diverse disciplines to adopt critical perspectives traditionally associated with formal design training (Meinel et al., 2020). Practicing DT allows individuals to generate deliberate, thoughtful decisions, enabling them to understand and address these complex problems (Löwgren & Stolterman, 2007). Therefore, DT has been shown to be instrumental in addressing wicked problems (Cankurtaran & Beverland, 2020), making it a vital skill in industries, business environments, and academia (Carlgren et al., 2016; Johansson-Sk¨oldberg et al., 2013; Matthews & Wrigley, 2017).

Research has shown that the DT skill sets are best acquired through structured educational programs that focus on fostering DT mindsets and abilities (Özcan, 2022; Razzouk & Shute, 2012). Several studies have highlighted the value of DT educa- tion at various levels, including K-12 (T. Li & Zhan, 2022; Rusmann & Ejsing-Duun, 2022), undergraduate (Ritchie et al., 2016), and graduate levels (Royalty et al., 2012). Along with these educational investigations, prior studies also showed that multi- disciplinarity in design thinking is vital because it brings together diverse perspectives and expertise, leading to more innovative and comprehensive solutions (Seidel & Fix- son, 2013). Although existing studies have proposed validated scales for measuring DT mindsets (Vignoli et al., 2023), perceived abilities (Coleman et al., 2020), and compe- tencies (Y.-L. E. Liu et al., 2023; Trung et al., (Trung 2024)), there remains a gap in developing a validated scale that measures the impact of an undergraduate DT curriculum in the context of DT mindsets and abilities of novice multidisciplinary teams. Contributing to this research gap is particularly critical, as diverse disciplinary environments are associated with being more conducive to successfully applying the DT process (Seidel & Fixson, 2013).

To address the identified gap, this research aims to develop a validated scale to measure a DT course's impact on novice multidisciplinary participants' mindsets and abilities and explore how such curricula influence their competencies. The course was designed for students across diverse fields, including administrative sciences, eco- nomics, engineering, law, medicine, and humanities. While prior studies have assessed the impact of DT within specific disciplines such as engineering (Greene et al., 2019) and nursing (H.-Y. Liu, 2024), a comprehensive assessment of DT's impact in a novice multidisciplinary environment remains underexplored. In contrast, the inclu- sion of team members from varied disciplines could enhance creativity and innovation by broadening the range of knowledge and perspectives brought to problem-solving (Fixson, 2009). This diversity could support more accurately identifying user needs, generating innovative ideas, and developing effective prototypes, enabling teams to address complex, cross-disciplinary challenges more comprehensively (Seidel & Fixson, 2013).

The curriculum is based on the IDEO model from the Design Thinking Toolkit for Educators (Riverdale & IDEO, 2012), which has been widely adopted and recognized for fostering innovation (Lee et al., 2021) and has been well received as students per- ceive the IDEO model as engaging and beneficial (Ching, 2014). The IDEO model's four key phases (Discovery, Interpretation, Ideation, and Experimentation) were adapted into an 11-week undergraduate course enriched with theoretical presentations, industry case studies, and practical assignments, such as observations, interviews, and video sketching (Zimmerman, 2005). Designed for students from diverse disciplines, the course emphasizes collaboration and multi-disciplinarity to enhance creativity, broaden perspectives, and address complex, cross-disciplinary challenges effectively (Seidel & Fixson, 2013).

Moreover, this study contributes a scale for measuring DT mindsets and abili- ties for participants of diverse disciplines and demonstrates that our DT curriculum significantly enhances students' mindsets and skills in multidisciplinary contexts. Fur- thermore, the validated scale developed here has strong potential for application in educational, business, and industrial settings where creativity and innovation are essential. By addressing the gap in assessing DT's impact in novice multidisciplinary environments, this research provides valuable insights for fostering DT competencies across fields.

## Related work

### Defining design thinking

Herbert Simon initially introduced the concept of design as a way of thinking in his book"The Sciences of the Artificial," (Simon, 1969), which has been the focus of many studies since then. However, the definition of design thinking appeared to be widely known after Buchanan coined the widely accepted definition in 1992 (Buchanan, 1992). For many years, it has remained a critical mindset highly valued and promoted across industry, academia, and business. Today, the DT approach influences many organizations' design culture by drawing from users' real-life experiences (Levy, 2017). Since Design Thinking has become widespread, the definition of design has expanded to encompass the design of services, processes, and systems (Verganti, 2009). The essence of design thinking lies not in the design itself but in the thinking process behind it (Tu et al., 2018). With this understanding, the DT approach is applied across various industries, including healthcare, engineering, technology innovation, law, and many others. (Razzouk & Shute, 2012). Design thinking revolves around placing users at the forefront of the process. This process starts with gathering user data before moving on to using insights as facilitators to design artifacts to address real needs and pain points (McKilligan et al., 2017).

Design thinking comprises many skills, such as critical thinking (Ericson, 2022), problem-solving (Matthee & Turpin, 2019), creativity, open-mindedness, and collabo- ration (Pande & Bharathi, 2020). However, scholars hold varying views of what design thinking is, as the prior studies focus on one aspect, such as its mindset (Martin, 2009), creative dimension (Kelley & Littman, 2001), or contributions in framing problems, visualizing, and constructing prototypes (Carlgren et al., 2016). Therefore, there is no one definition of design thinking. Instead, according to IDEO, it is a set of mindsets and design activities that enhance collaboration to solve problems from a human-centered approach (IDEO. Designthinking.Ideo.com, n.d.). In this study, we adopt the perspective of IDEO.

### Design thinking models, mindset and abilities

Numerous design thinking models have surfaced over time. These models are tailored to specific objectives, such as education, business, or fieldwork, that consist of a series of iterative steps to foster innovation (Nakata & Hwang, 2020). The primary distinction between these models lies in the terminology used for each stage of the DT process.

The overall perspective of design thinking impacts the naming and decomposi- tion of the processes. For instance, Banfield et al. (2016) view DT as a design sprint process that goes through five consecutive stages: (1) understand, (2) diverge, (3) converge, (4) prototype, and (5) test (Banfield et al., 2016). Moreover, the Evolution 6sq framework takes its name from the evolutionary and iterative nature of the pro- cess. As the name suggests, the model is divided into six phases, all beginning with E: Emergence, Empathy, Experimentation, Elaboration, Exposition, and Extension (Tschimmel, 2018).

Some other models construct their structure regarding the DT activities. LUMA Institute concentrates on the activities of the process and advocates for a three-phase framework consisting of looking, understanding, and making (LUMA Institute, 2012). In a similar understanding, Liedtka introduces a framework building on DT actions. This framework is organized in a four-question structure:"What is? What if? What wows? And what works?" (Liedtka & Ogilvie, 2011).

Within educational contexts, d.school's' Hasso Plattner model' (Plattner et al., 2012) and IDEO's' Educational Toolkit' (Riverdale & IDEO, 2012) are put into practice. Despite each stage being named differently in these two models, both have stages with similar goals and follow a dynamic and non-linear framework. Here, we mainly focus on IDEO's model, and according to its educational model, the five stages are (1) discovery, (2) interpretation, (3) ideation, (4) experimentation, and (5) evolution. After implementing the Educational Toolkit in 2012, the IDEO team extended their learnings to further inform fieldwork in real-life applications (IDEO, 2015).

All of these approaches have the same underlying logic and revolve around the idea of being human-centered. Ericson identifies five common points of the DT models (Ericson, 2022). First and foremost, a diverse and multidisciplinary team is necessary to include diverse perspectives. Secondly, this team gets involved with divergent think- ing to employ user-centered methods and collects data to empathize with a target audience. Third, the team needs to apply convergent thinking methods to filter user insights and tame the wicked problem (Buchanan, 1992). In the later stages, research- based assumptions are tested by developing prototypes. Finally, the prototypes are evaluated through many iterations.

In our study, we adopted IDEO's' Educational Toolkit model (Riverdale & IDEO, 2012) as we focused on crafting our course in a multidisciplinary educational setting. We chose to adopt this model as our foundation due to its long history of creat- ing successful products. For instance, IDEO's founder, David Kelley, was involved in designing Apple's first computer mouse (Prud'homme Van Reine, 2017). IDEO's model has demonstrated practical applicability in company cultures through numer- ous real-life examples, including Airbnb, Netflix, and Uber (Poleac, 2023), making it the most relevant model to serve as the foundation for a Design Thinking course.

A significant aspect of DT is the mindset and abilities required to implement these various models effectively. Considering this, Design Thinking is often equated with a skill set and/or toolset (Howard et al., 2015). Three distinct terminologies (i.e., tools, actions, and mindset) describe the DT skill set (Vignoli et al., 2023), which focus on different aspects of DT's outcomes. *Tools* are the pieces of equipment that can be applied in the DT process (Liedtka, 2015), such as writing how-might-we questions, conducting interviews, and creating storyboards. Using these tools, *actions* define the activities that collectively drive progress (Nakata & Hwang, 2020), such as defining problems and ideating. *Mindset* refers to the analytical and knowledge-based components of the DT process (Vignoli et al., 2023). When these diverse aspects come together, individuals can develop the Design Thinking skill set and enhance their competency in Design Thinking (Razzouk & Shute, 2012). Consequently, it is essential to examine these distinct elements in an integrated manner.

## Design thinking in education

Tim Brown, the chair of IDEO, expresses that the most significant opportunity for the long-term impact of design thinking can be achieved through education (Brown & Katz, 2019). As design thinking becomes integrated into the educational context, tradi- tional thinking in any problem-solving process is losing ground (Johansson-Sk¨oldberg et al., 2013). In this transforming landscape, Design Thinking is used in many different educational contexts, spanning from K-12 education to higher education institutions. DT skills are developed in these settings through pedagogical approaches such as problem-based research, project-based learning, and inquiry-based learning within classroom activities (Dym et al., 2005).

Employing design thinking in K-12 education was demonstrated to improve students" active learning, collaboration (Carroll et al., 2010; Rusmann & Ejsing-Duun, 2022), research and information fluency, critical thinking, and creative confidence (Goldman & Zielezinski, 2016; Lin et al., 2024) skills, as well as supporting students' STEM (Science, Technology, Engineering, and Mathematics) learning and fostering interest in STEM (Mentzer et al., 2015). Learning such skills is essential for students to adapt to a constantly evolving and changing world (Goldman & Zielezinski, 2016). To achieve integration of DT in K-12 curricula, Kolodner et al. suggest that the Learning by Design approach, which uses project-based inquiry and design challenges in middle school science education, can be adapted to integrate Design Thinking at these educational levels (Kolodner et al., 2004). The most crucial learnings of this approach to carry through to higher education involve facilitating the learning process through numerous iterations and providing social affordances like sharing and reflecting to promote the feeling of success.

On top of these, higher education institutes, such as universities and colleges, increasingly integrate the DT mindset to respond to the need to develop skills compatible with the twenty-first century (Johansson-Sk¨oldberg et al., 2013; Özcan, 2022). In light of this, universities are upgrading their curriculum to incorporate various disciplines like social science, engineering, humanities, cultural studies, and management studies to collaborate effectively (Levy, 2017). Moving in this direction aims to equip university students with the skills needed to meet the evolving demands of industry and society, focusing on bridging the gap between technology producers and consumers (Bridle et al., 2013). Research indicates that to achieve a meaningful impact, curriculums have to be designed to facilitate students" familiarity with each other's' fields and develop an openness to diverse perspectives (TaneLi et al., 2013).

In addition to this, the content and objectives of design thinking courses vary among higher education institutes based on their integrated structures. Some institu- tions offer specialized design thinking courses, while others design thinking principles into a few weeks or days of broader department courses (Abdulghany et al., 2022). For instance, Design Thinking is offered as a standalone course at design thinking schools in Potsdam and Stanford (Jobst et al., 2012), which follow the d.school model from the Hasso Plattner Institute of Design at Stanford University (Plattner et al., 2012). Contrarily, in engineering disciplines, the DT mindset is often incorporated into the course's objectives (Fila et al., 2018). For example, creative problem-solving and active learning through iterative design thinking approaches were incorporated within an upper-level undergraduate engineering course (Clark et al., 2018), and the duration of these particular group-based classes was extended due to the nature of the active learning process.

However, studies from designerly perspectives suggest that integrat- ing insights from design education and incorporating various learning stages in design are crucial for effectively teaching design thinking (Lattemann et al., 2020). For this reason, we carefully crafted the multidisciplinary environment for a semester-long DT course that serves as a foundation for all the motivations mentioned above.

### Measuring impact in design thinking education

Upon integrating design thinking into diverse educational contexts, research also delved into understanding the impact of design thinking on the students' skill set development. These studies embody different qualitative and quantitative methods.

The objective of qualitative methods in this scope is to provide in-depth insights into which aspects of DT skills the students improved and how they achieved these improvements (Carroll et al., 2010; King & McCall, 2024; McKilligan et al., 2017). For instance, Carroll et al. (2010) conducted semi-structured interviews with 24 seventh- grade students, their teacher, four university design school instructors, and five small- group mentors (graduate students) within the three weeks of a middle school DT course. This study aimed to gather their distinct perspectives as they engaged in design activities for the first time in the classroom context (Carroll et al., 2010). As a result they observed that design thinking impacted students by encouraging exploration, connection, and intersection activities.

On the other hand, the impact of design thinking is also measured through scale development (Dosi et al., 2018; Greene et al., 2019; Vignoli et al., 2023). In recent years, researchers have acknowledged that scale development involves a comprehensive study from design to implementation, leading to the use of mixed methods in this process (Zhou, 2019). Therefore, scale development can encompass both quantitative and qualitative methodologies. Qualitative phases include instrument development and a confirming step to test the instrument (Creswell & Plano Clark, 2011). On the other hand, quantitative methods consist of constructing quantitative instruments such as developing Likert-format scales (Onwuegbuzie et al., 2010).

With this in mind, various scales related to design thinking have been developed for different objectives. These include measuring the impact of DT with professionals who are experienced with DT activities (Dosi et al., 2018), understanding the attitudes of engineers and engineering students towards integrating DT in engineering contexts (Coleman et al., 2020; Greene et al., 2019), eliciting the correlation between multidis- ciplinary engineering students' opinions on critical thinking and their ability in design thinking (Suligoj et al., 2020), and comparing the DT skills over short-term (one week- end) and long-term (10 weeks) design challenges of third-year students enrolled in a 12-week biomedical design and management course within the biomedical engineering department (Davies et al., 2023).

In essence, these studies have shown that taking a design thinking education, whether a short sprint or a semester-long course, improved skills associated with DT. However, the extent of improvement in DT skills varies across different contexts. Research indicates that short-term and long-term learning outcomes differ due to the collaboration process among team members (Davies et al., 2023) and the background of the students (Marshall, 2013). Davies et al.'s (2023) study revealed that students built more abilities through the structured engagement process in the long-term course. Therefore, while these studies illuminate the positive impact of Design Thinking in higher education and business settings, they leave an opportunity to explore its appli- cation across various disciplines in educational settings over a full-term undergraduate university course. To address this need, we have developed a scale for measuring its effectiveness and integration in multidisciplinary contexts.

## Methodology

Upon designing the Design Thinking curriculum to be implemented for a semester- long undergraduate course for students from diverse disciplines, our research process includes the following steps shown in Fig. 1.

### Our design thinking curriculum

Design thinking curricula adopt a human-centered, inquiry-driven approach, fostering exploration of challenges with a problem-solving mindset (Aflatoony et al., 2018). Therefore, given the practice-based nature of this course and the diverse academic backgrounds of the students, we structured the curriculum to emphasize collaborative, group-based learning.

To implement this collaborative learning approach, we adapted IDEO's five-stage educational toolkit model (discovery, interpretation, ideation, experimentation, and evolution) to fit the constraints of our 11-week undergraduate course (Riverdale & IDEO, 2012). Due to the limited teaching weeks in a university setting, we priori- tized the first four stages, dedicating less focus to the evolution phase, which typically requires multiple iterations to refine ideas into more polished outcomes. Additionally, we restructured IDEO's framework into a hybrid format that combines lectures with hands-on, practice-based activities (Fig. 2). This adaptation includes integrating theoretical concepts such as cryptomnesia and practical tools like video sketch- ing, marking unique contributions to the IDEO toolkit within our design thinking curriculum.

To establish a solid foundation, we extended the Discovery phase—encompassing problem definition—across the first four weeks of the course. We defined design and design thinking in the introductory lecture (Week 1). We presented various DT mod- els such as the Stanford d.school approach (Auernhammer & Roth, 2021), Jeanne Liedtka's' framework (Liedtka & Ogilvie, 2011), and the Luma Institute's' model (LUMA Institute, 2012), and highlighted their shared principles. This introduction helped students grasp the essential components of a design thinking process. Sub- sequently, we formed multidisciplinary groups of 5–6 students, ensuring diversity in academic disciplines and university years. In Week 2, we enriched the curriculum with industry case studies demonstrating design thinking in practice. In Week 3, we

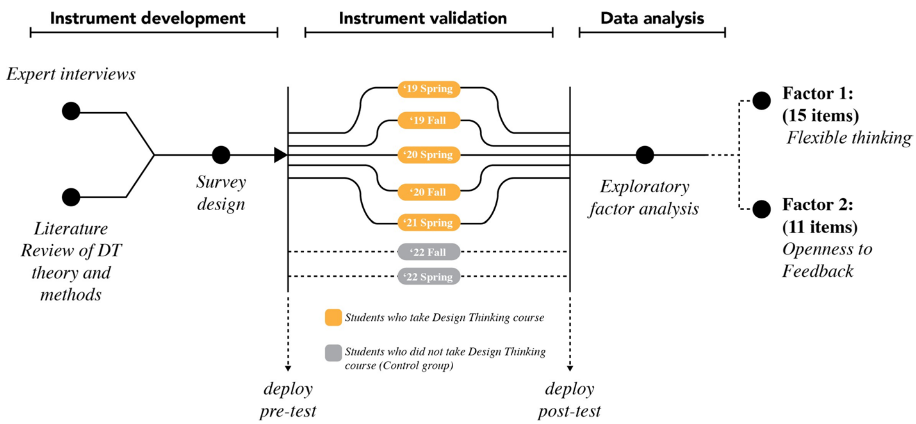



**Fig. 1** Research design

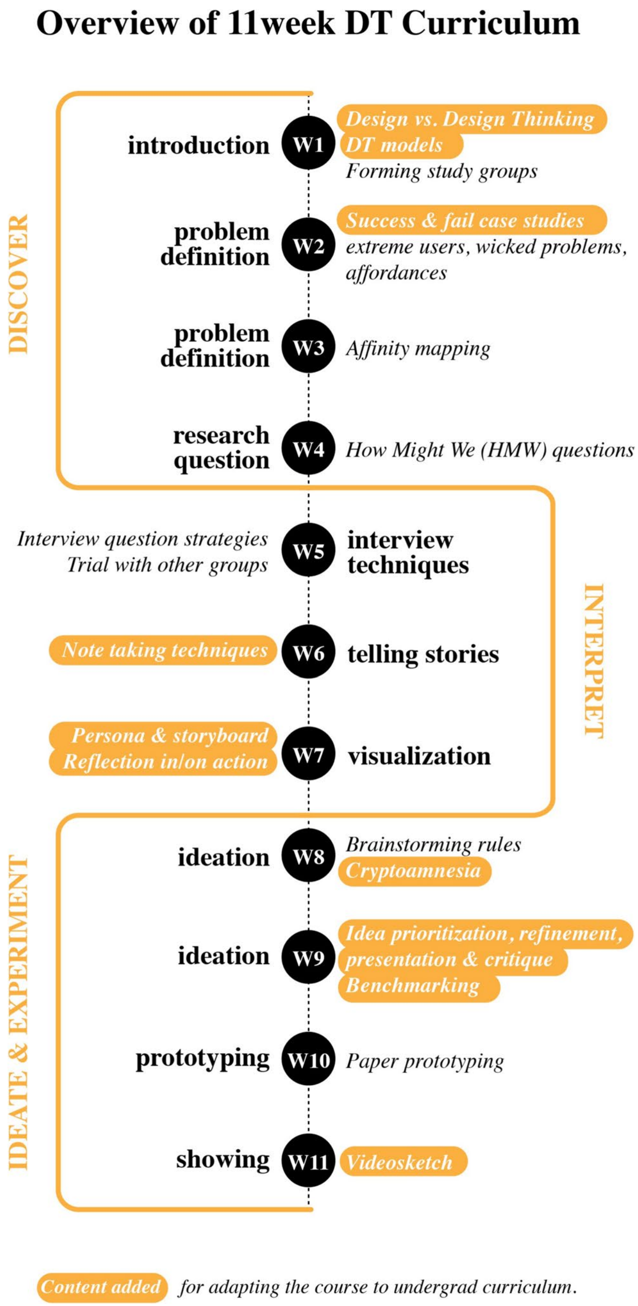



**Fig. 2** Our Design Thinking Curriculum

also introduced key concepts, including extreme users (Raviselvam et al., 2022), wicked problems (Buchanan, 1992), and affordances (Gibson, 1977). During this phase, stu- dents actively observed users in their natural environments, mapped the problem space, and formulated"How

Might We" (HMW) questions in Week 4 (Siemon et al., 2018). This user-centered approach enabled students to develop adaptable, transfer- able skills, emphasizing the ability to define problems from scratch rather than relying on predefined scenarios (Mentzer et al., 2015). During the three weeks of the Inter- pretation phase (Week 5–6-7), students developed and refined interview questions, conducted user interviews, and analyzed qualitative data to gain deeper insights into the problem. As a novel addition to the IDEO model, we encouraged them to pilot their interview questions with other groups in class, provided guidance on effective note-taking techniques, and introduced the concept of reflection in/on action, under- scoring the value of visual thinking throughout the process (Schön, 1983). Note-taking techniques provided students with strategies to effectively capture and organize key details, ideas, and information related to their interview process (Peverly et al., 2003). Additionally, reflection in/on action, as developed by Donald Schön (1983), involves using sketches and visuals as tools to think critically about one's work and improve future performance. It could be done both during the activity (in action) and after (on action).'In Action' could be described as quickly sketching ideas, observations, or problems while working on a project that can help you visualize and analyze the situ- ation, leading to immediate adjustments and new directions. For example, a designer might sketch different layout options while working on a website, reflecting on each and making real-time changes.'On Action', meanwhile, could be described as after completing a task or project; drawing can help you recall and analyze the experience. Sketching key moments, interactions, or challenges can trigger deeper thinking and insights that might be missed with just written notes. For example, a teacher might draw a classroom scene after a lesson to reflect on student engagement and identify areas for improvement. In addition to those mentioned above, visual tools such as per- sonas and storyboards were introduced to help students interpret and articulate their problem space more effectively. The Ideation and Experimentation phases, spanning the last four weeks (week 8,9,10,11), introduce students to design activities like sketch- ing, hands-on prototyping (IDEO, 2015), and video sketching (Zhang et al., 2021). Video sketching is a rapid prototyping technique where individuals draw their ideas on traditional paper, whiteboard, or digitally while narrating their thought process.

out loud (Zimmerman, 2005). In this technique, students articulate their design nar- ratives by engaging in role-playing with rudimentary paper prototypes. This process is documented through sequential photographs, capturing the functionality and user interaction with the prototype. These photographs are then compiled into a sequential presentation format, akin to a slideshow, facilitating visualization and comprehension of the design concept. This method enables iterative feedback and refinement, foster- ing collaborative critique and improvement of the design, and also allows for quick iteration and feedback on design concepts, similar to how paper prototyping is used for testing user interfaces. The traditional IDEO model often incorporates a making stage where participants physically create prototypes. However, creating only a phys- ical prototype approach necessitates specialized infrastructure, limiting accessibility and mobility for educational purposes. We integrated the video sketching technique into the model to address this constraint. Based on our observations, this novel adap- tation triggers a broader variety of refined ideas while circumventing the limitations of physical prototyping because it is quicker, easier, requires no specialized infras- tructure, and is more affordable (Fig. 3). Thus, it enhances the accessibility and flexibility of design thinking education.

In these lectures, we also paid attention to incorporate related information from other fields. For example, as a novel addition to the curriculum, before the ideation stage, we introduced the concept of"cryptomnesia," the unintentional recall of ideas previously encountered, often mistaken for original thoughts (Br´edart et al., 2003). To address the issue of cryptomnesia, we introduce"guerrilla thinking," forcing peri- ods, such as challenging students to generate 20 ideas in 5 min. Students begin by sketching as many ideas as possible in this short period.

In this strategic task, they initially present familiar ideas, often unconsciously recalling those seen on social media (Marsh & Rajaram, 2019). However, as they are pushed toward the end of the time limit, they begin to generate seemingly absurd ideas without overthinking. We have observed that these seemingly absurd ideas often transform into more innovative solutions. Sharing and comparing these sketches with peers usually reveals common solutions, encouraging them to push beyond generic ideas and explore more unique, original solutions. Although cryptomnesia does not have a definitive solution in sci- ence (Dow, 2015), we have observed that this technique helps students overcome it as much as possible. Furthermore, students experienced presentations and critique ses- sions with other students in the class and learned how to benchmark their prioritized ideas. Aligned with the above-mentioned concepts of paper-prototyping (Snyder, 2003) and video-sketching (Zimmerman, 2005), these experiences helped students present and refine their ideas better throughout the DT process.

The whole process was to enable students to implement the core DT values into practice-based experiences (Fig. 4). For instance, in the Discovery phase, students learn strategies for managing complex challenges and turning to problems in a manageable way; while in the Ideation and Experimentation phases, they practice reflection by evaluat- ing and iterating on each other's ideas. Throughout the course, we reminded students of the iterative nature of the design thinking process, reinforcing that each phase builds on the last and encourages ongoing refinement (Stickdorn & Schneider, 2011). Based on the authors' extensive teaching experience, this curriculum combines theo- retical insights and hands-on practice to address common misconceptions and enrich students' design-thinking skills.

## Instrument development

We followed an inductive approach to item generation (Kapuscinski & Masters, 2010), consisting of two phases. First, we conducted a survey with open-ended questions targeting Design Thinking experts (N = 7) (Step 1). Then, combining the inductive insights from the expert responses with findings from existing DT literature, we devel- oped 48 survey questions, finalizing the instrument (Step 2). Throughout the research process, all of the recruited DT experts were identified based on several criteria obtained from previous studies. Prior research identified the value of learning through teaching DT to become an expert in utilizing theoretical knowledge and navigating practical facilitation experience (Henriksen et al., 2020; Morehen et al., 2013). Another.

study specifically identified the importance of a common ground of a DT model for identifying DT experts, because each DT model and its interpretation had a direct impact

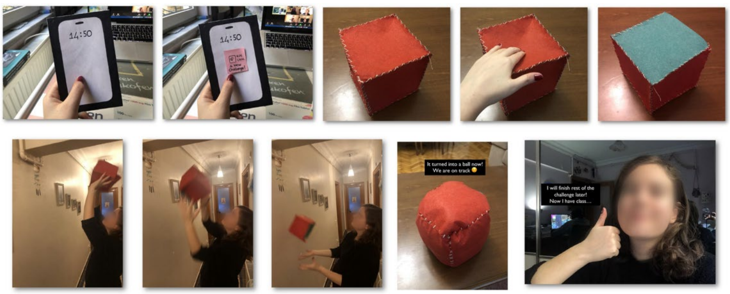



**Fig. 3** An example video sketch

**Fig. 4** Students in the design thinking course

on the experts' theoretical knowledge and facilitation practice (Starostka et al., 2021). Therefore, all the DT experts who participated in this research met the fol- lowing recruitment criteria: (1) who accomplished at least four completed semesters facilitating a DT course that employs IDEO's DT model, (2), and affiliated with a higher education institution. All of these experts were part of our research group, and one of them is the corresponding author of this research, who led the process. Below, we describe the instrument development process in Fig. 5

Step 1 —Expert Survey

To initiate the development of our instrument items, we investigated the goals and outcomes of the DT course from the perspective of experts, a widely used practice in scale development (Morgado et al., 2017). We administered a Qualtrics survey with 14 open-ended questions to DT experts who had facilitated DT courses for at least four semesters. The minimum number of semesters for facilitation was preferred to establish a common ground for each facilitator's DT expertise. In particular, two of these experts were actively

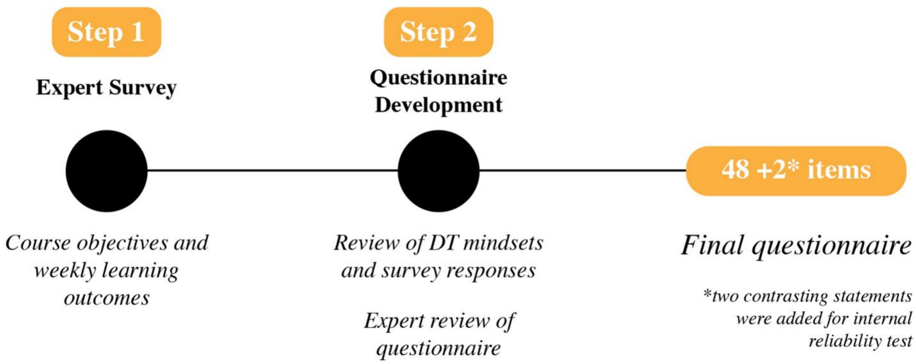



**Fig. 5** Instrument development roadmap

involved in designing the course. Their experience in teaching DT was instrumental in identifying relevant skills for under- graduates. Prior studies also highlight the importance of expert insight in fostering DT mindsets and abilities in students (Mosely et al., 2018).

We contacted 12 DT experts who met our facilitation expertise criteria and received responses from 7. The survey asked about (1) the course objectives and (2) the weekly learning outcomes expected for undergraduate students. Based on their expertise, these open-ended questions allowed experts to express the core skills and competencies students should gain in a DT course.

The experts' responses underscored key competencies such as hands-on thinking, collaborative working, and adaptability to iterative processes—skills central to the DT course. Their feedback was essential in forming the basis of our instrument.

Step 2 —Developing the Final Version of the Questionnaire

After gath- ering insights from the expert survey, we realigned these findings with our previous literature review to expand on the identified DT mindsets. Based on this, we devel- oped an initial 48-item questionnaire. Each item reflected key insights from the expert responses and literature review. We then convened with three additional DT experts who applied deductive coding to ensure each item mapped to the DT mindsets (IDEO, 2015;Lahiri et al., 2021; Liedtka, 2015; Nakata & Hwang, 2020; Vignoli et al., 2023), resulting in the final version of the 48 items.

## Data collection and analysis

### Measures and study procedure

The 48 self-report items were measured using a five-point scale. Each item in the questionnaire used a five option response scale of: 1 = "I cannot do this at all"; 2 = "I cannot do it"; 3 = "I am unsure whether I can or cannot"; 4 = "I can do it"; 5 = "I can do it very well." The questionnaire was distributed to course participants at two points in the semester: once at the beginning (pre-test), when students had no prior DT experience, and again at the end of the semester (post-test) after engaging with DT methods and practices. This approach allowed us to measure the development of the DT abilities over the semester. The instrument was distributed to the class by the DT experts who facilitated the course.

The questionnaire was distributed in the class through a hyperlink that directed participants to Qualtrics. Participants were able to participate using any device they had (phone, tablet, laptop) with an internet connection. Responses to the questionnaire were collected anonymously and took approximately 15 min to complete.

### Participants

Participants of this study are university students who took the Design Thinking (DT) class during the Fall and Spring semesters from 2019 to 2022 (except the 2021 Fall semester) and took the survey we constructed as shown in Fig. 5. The DT course was designed as an entry-level elective course offered to students enrolled in Ko¸c Univer- sity's administrative sciences, economics, engineering, law, medicine, and humanities departments. We set equal quotas for each department to ensure that a multidisci- plinary group of students attended the course. Enrollment in the course was open to students at all levels, resulting in a variety of respondents, ranging from first-year students to seniors.

In total, data was collected from 340 undergraduate students who attended the DT course. Participants were required to fill out the pre-test survey in the first class of the semester and the post-survey in the last class. Participants who did not complete either one of these surveys were excluded from the sample (n = 53), resulting in a final sample size of 287.

### Data screening

The data was screened for missing values and univariate outliers. Univariate outliers were defined as cases with standardized z-scores exceeding ± 3.29 on any item, following conventional thresholds for large samples. 11 participants were excluded from the analysis due to missing values. With a final sample size of 276, there were over 5 cases per variable. The sample size was considered adequate for exploratory factor analysis, as it exceeded the commonly recommended ratio of at least five participants per item (Tabachnick et al., 2007).

### Factor analysis

A principal component analysis was conducted only for pre-assessments. Initially, the factorability of the 48 items was examined for the pre-test. Several well-recognized criteria for the factorability of a correlation were used. A total of 46 out of the 48 items correlated at least 0.30 with at least one other item, suggesting reasonable factorability. The Kaiser–Meyer–Olkin measure of sampling adequacy was 0.84, which can be inter- preted as very good and above the commonly recommended value of 0.6, and Bartlett's' test of sphericity was significant ($\chi^2(1228) = 4421,\ 118,\ p < 0.01$). The diagonals of the anti-image correlation matrix were also all over 0.5 and the commonalities were all above 0.5, further confirming that each item shared some common variance with other items. Given these overall indicators, factor analysis was deemed to be suitable using all 48 items.

### Focus group discussions for interpreting factors

To interpret factor analysis, there are several studies that support the analysis pro- cess with step-by-step guidance. Williams et al. (2010) proposed a 5-step guide for conducting factor analysis, in which it described its interpretation phase as giving the factor a name or a theme to explain the majority of responses together (Williams et al., 2010). Also, the proposed guide by Carpenter (2018) highlights the importance of reporting on reasoning and decisions made at key phases in the scale development pro- cess, such as the interpretation of resulting factors (Carpenter, 2018). Mixed-method perspectives, such as interviews and focus group discussions in factor analysis, are also considered valuable in prior research (Leech et al., 2010). Therefore, we inte- grated a focus group discussion with five DT experts (who taught/facilitated DT for at least 4 semesters) to better give names and themes regarding the resulting two-factor structure of our analysis.

In the focus group discussions, experts have associated each item in the resulting factor structure with (1) the goals and mindsets the DT course aims to provide, (2) which DT stage the item is related in the IDEO's model, and (3) how the item is related to the other items in the factor structure. The discussion session lasted around one hour and 15 min and was audio-recorded for deeper elaboration. Furthermore, the names and descriptions of the resulting factors were concluded upon consensus with the participating experts at the end of the focus group discussion.

## Results

### PCA for the pre-test

Principal components analysis was used because the primary purpose was to identify and compute composite scores for the factors underlying the short version of the survey. Initial eigenvalues indicated that the first three factors explained 19%, 7%, and 6% of the variance, respectively. The rest of the 14 factors had eigenvalues of just over one, and each explained 4 and 2% of the variance. Solutions for one, two, and three factors were examined using the varimax rotation of the factor loading matrix. The two-factor solution was preferred because of (a) its previous theoretical support, (b) the"leveling off' of eigenvalues on the scree plot after two factors (see Appendix A

), and (c) the insufficient number of primary loadings and difficulty of interpreting the third and subsequent factors. To determine the appropriate number of factors, we examined eigenvalues, the scree plot (provided in Supplementary Materials), and the interpretability of the resulting factor structures. The elbow of the scree plot supported a two-factor solution. While one- and three-factor models were also explored, the two- factor model best aligned with our theoretical framework and showed clearer factor separation. Although both varimax and direct oblimin rotations were initially tested, varimax was ultimately preferred due to the moderate correlation between factors ($r=0.40$) and our conceptualization of the two constructs as relatively distinct yet co-occurring dimensions.

At first, a total of 13 items (42, 24, 7, 5, 44, 47, 13, 41, 20, 38, 30, 14, 12) were eliminated because they did not contribute to any factor structure, failed to meet a minimum criterion of having a primary factor loading of 0.4 or above, and had cross- loadings on two factors. Second, nine more items (39, 34, 17, 22, 50, 2, 32, 36, 35) were eliminated since they also had cross-loadings on both factors.

For the final stage, a principal components analysis of the remaining 26 items, using varimax rotation, was conducted, with the first factor explaining 21% of the variance and the second factor explaining 14% of the variance. A varimax rotation provided the best-defined factor structure. All items in this analysis had primary loadings of at least 0.4, onto alternative factor above 0.32, and demonstrated a difference of at least 0.2 between their primary and alternative factor loadings. The factor loading matrix for this final solution is presented in Table 1.

The factor labels proposed by Frydenberg and Lewis (1993) suited the extracted factors and were retained (Frydenberg & Lewis, 1993). Internal consistency for each of the scales was examined using Cronbach's' alpha. The alpha for all the items was high:

0.86. The Cronbach's alpha value for the first factor (Flexible Thinking) was 0.87, and for the second factor (Openness to Feedback), it was 0.77. Thus, there were 15 items in the first factor and 11 items in the second one. The skewness and kurtosis were well within a

**Table 1** Rotated component matrix for each item

| Item | Factor 1: Flexible Thinking | Factor 2: Openness to Feedback |
|---|---|---|
| 45. When generating ideas about a topic or problem, I can set aside my previous thoughts and assumptions related to the subject | 0.772 | |
| 1. I can generate a large number of alternative ideas about a topic or problem | 0.721 | |
| 4. When generating ideas about a topic or problem, I let my imagination speak | 0.703 | |
| 15. When generating ideas about a topic or problem, I can think in a versatile manner | 0.697 | |
| 28. I find it necessary and meaningful to seek ideas from people I find related to the topic I am addressing (for example, if I am thinking about a topic related to operating rooms, I would talk to doctors, nurses, or patients) | 0.629 | |
| 27. When generating ideas about a topic or problem, I can think beyond the existing solutions | 0.628 | |
| 10. I can analyze and interpret the qualitative (non-numerical) information I obtain about the topic I am addressing | 0.576 | |
| 26. I am curious and eager to generate as many ideas as possible about a topic or problem | 0.551 | |
| 33. I can identify similarities among the different findings I obtain about the topic I am addressing and find connections | 0.548 | 0.304 |
| 25. I know and can use the necessary methods to effectively convey my ideas concisely and efficiently to the recipient | 0.522 | |
| 23. When conveying my ideas about a topic to others, I prefer to show and experience them (through drawings or by materializing/creating) rather than just explaining | 0.519 | |
| 21. I can apply the methods I have applied and observed to be effective on a topic or problem in everyday life in other situations as well | 0.499 | |
| 3. I am skilled at critiquing the ideas and thoughts of others to help move them to a better point | 0.490 | |

**Table 1** (continued)

| Item | Factor 1: Flexible Thinking | Factor 2: Openness to Feedback |
|---|---|---|
| 46. When I start generating ideas about a topic or problem, I tend to quickly and directly reach a conclusion | 0.418 | |
| 9. I can formulate questions about a topic of interest in a way that allows me to conduct research on it | 0.397 | |
| 48. When addressing a topic or problem and presenting multiple solutions, I can objectively eliminate ideas based on set criteria | | 0.698 |
| 16. When thinking about a problem, I make an effort to consider not only my own perspective but also those of others | | 0.594 |
| 43. When generating ideas about a topic or problem, I tend to think that the first idea that comes to mind is correct | | 0.589 |
| 40. When generating ideas about a topic or problem, I continue to think based on the first alternatives that come to mind | | 0.572 |
| 8. When addressing a topic or problem, I am curious about others' thoughts and perspectives | | 0.563 |
| 6. I am skilled at collaborating with multiple individuals and dividing tasks effectively | | 0.557 |
| 19. When I receive negative feedback on my ideas about a topic, I tend to defend them without thinking | 0.312 | 0.515 |
| 29. Before generating ideas about a topic or problem, I conduct research on the subject | | 0.479 |
| 37. When working on a topic, I prioritize the success of the team I am part of over my individual success | | 0.477 |
| 11. When I receive feedback from someone else on my ideas/creations/presentations, I immediately start thinking about the negative points | | 0.475 |
| 31. When I receive feedback from someone else on my ideas/creations/presentations about a topic, I notice and perceive the thoughts/con- cepts created in the other person by my ideas/creations/presentations | | 0.395 |

**Table 2** Descriptive statistics for two-factor solution (N = 276)

| | M | SE | SD | Skew | Kurt |
|---|---|---|---|---|---|
| Total | 3.81 | 0.3 | 0.37 | −0.413 | 2.636 |
| Factor 1: Flexible Thinking | 3.71 | 0.3 | 0.46 | −0.409 | 1.523 |
| Factor 2: Openness to Feedback | 3.96 | 0.3 | 0.41 | −0.612 | 1.193 |

**Table 3** Pearson's' correlation coefficients between two factors and the total mean

| | 1 | 2 | 3 |
|---|---|---|---|
| (1) Factor 1: Flexible Thinking | 1 | | |
| (2) Factor 2: Openness to Feedback | 0.398** | 1 | |
| (3) Total Mean | 0.906** | 0.738** | 1 |

**$p < 0.01$

tolerable range for assuming a normal distribution, and examination of the histograms suggested that the distributions looked approximately normal.

## Descriptive findings

Descriptive statistics for the two-factor solution are given in Table 2. Even though the total mean looked slightly heavy-tailed, it was decided that it was tolerable at this point.

## Relationship between two factors

Pearson's correlation coefficients were used to investigate the relationship between the factors and the total mean score. Results can be seen in Table 3.

## Comparison between pre- and post- tests

The mean scores for each factor for pre- and post-assessments were compared to investigate the two-factor solution further. At this point, the number of participants who took both pre- and post-assessments was 162 (control: 34, experimental: 128).

Measuring the impact of DT using the two factors based on ANOVA and ANCOVA analysis.

Parametric ANOVA and ANCOVA models were used as the assumptions of normality, homogeneity of variances, and independence were assessed and met. Normality was supported by skewness and kurtosis values within acceptable ranges and visual inspec- tion of histograms. Levene's test indicated that variance homogeneity was not violated for Factor 2; for Factor 1, Bonferroni-adjusted tests were used when the assumption was not fully met.

### ANOVA results for factor 1: Flexible thinking

A 2 (pre- and post-assessment) x 2 (group: control and experimental) ANOVA was conducted to investigate the effects of two independent variables, namely pre-post assessment and group, on the dependent variable, mean scores for Factor 1. Box's test of equality of covariance matrices was statistically significant (p <.01), indicat- ing a violation of the assumption of homogeneity of covariance matrices. Bonferroni correction was applied for multiple comparisons.

While the main effect of the group was not significant ($p = 0.386$), the main effect of assessment was significant, $F$ (1, 160) = 46.02, $p < 0.001$, $\eta 2 = 0.22$. Specifically, the mean of post-assessment ($M = 4.00$, $SE = 0.04$) was higher than pre-assessment ($M = 3.73$, $SE = 0.05$). The interaction between assessment and group was also sig- nificant, $F$ (1, 160) = 19.26, $p < 0.001$, $\eta 2 = 0.11$. Pairwise comparisons revealed that experimental group's post-assessment scores ($M = 4.06$, $SE = 0.04$) were significantly higher than their pre-assessment scores ($M = 3.61$, $SE = 0.04$) and this difference was not observed in control group (Pre-assessment: $M = 3.85$, $SE = 0.05$; Post-assessment: $M = 3.95$, $SE = 0.08$).

### ANOVA results for factor 2: Openness to feedback

A 2 (pre- and post-assessment) × 2 (group: control and experimental) ANOVA was conducted to investigate the effects of two independent variables, namely pre-post assessment and group, on the dependent variable, mean scores for Factor 2. Box's test of equality of covariance matrices revealed a non-significant difference (p = 0.100), indicating the assumption of homogeneity of covariance matrices was met. Bonferroni correction was applied for multiple comparisons.

The main effect of the group was significant, $F$ (1, 160) = 10.810, $p = 0.001$, $\eta 2 = 0.06$. In detail, the mean scores of the experimental group (M = 4.15, SE = 0.03) were higher than the control group ($M = 3.91$, $SE = 0.07$) for factor 2. The main effect of assessment was also significant, $F$ (1, 160) = 24.320, $p < 0.001$, $\eta 2 = 0.13$. Again, the mean scores for the post-assessment (M = 4.12, SE = 0.04) were higher than pre- assessment scores ($M = 3.93$, $SE = 0.04$). The interaction between assessment and group was significant, $F$ (1, 160) = 13.24, $p < 0.001$, $\eta 2 = 0.08$. Even though there was no significant difference between control ($M = 3.88$, $SE = 0.08$) and experimental groups ($M = 3.98$, $SE = 0.04$) in pre-assessment, experimental group ($M = 4.31$, $SE = 0.04$) had significantly higher scores than control group ($M = 3.93$, $SE = 0.08$) in post- assessment. Moreover, the experimental group's mean score increased from pre- ($M = 3.98$, $SE = 0.04$) to post- ($M = 4.32$, $SE = 3.98$) assessments, but there was no difference in the control group's pre- and post-assessment mean scores.

### ANCOVA results for factor 2: Openness to feedback

To compare post-assessment scores between the control and experimental groups while controlling for pre-test scores, an analysis of covariance (ANCOVA) was conducted. First, we checked the independence of the covariate assumption by conducting an independent t-test in which mean pre-assessment scores were the dependent variable and group was an independent variable. Results indicated that mean pre-assessment scores were significantly different between each group for factor 1, t (87) = 3.60, p < 0.001, Cohen's' d = 0.524. On the other hand, there were no group differences in mean pre-assessment scores for factor

2 ($p = 0.106$). Therefore, assumptions for ANCOVA were not met for the first factor, and ANCOVA was conducted only for factor 2.

ANCOVA was performed to compare post-assessment scores between the con- trol and experimental groups while controlling for pre-test scores for Factor 2. Levene's test indicated that the assumption of homogeneity of variances was met, $F$ (1, 160) = 0.72, $p = 0.397$. The ANCOVA yielded a significant main effect of group, $F$ (1, 160) = 20.95, $p < 0.001$, $\eta 2 = 0.116$. Participants in the experimental group ($M = 4.31$, $SE = 0.03$) had significantly higher post-assessment mean scores compared to those in the control group ($M = 3.98$, $SE = 0.06$), after controlling for pre-assessment scores. Pairwise comparisons using Bonferroni adjustment indicated a significant mean difference between the control and experimental groups, with the experimental group scoring higher (*meandifference* = 0.317, $SE = 0.069$, $p < 0.001$, 95%*CI*[0.180, 0.454]).

Overall, the results suggest that participation in the experimental group led to significantly higher post-assessment scores compared to the control group, even after controlling for pre-assessment scores.

## Discussion

In this study, we developed a scale to measure the impact of a Design Thinking (DT) mindset and abilities through education. We tested this scale to measure across five semesters of our multidisciplinary undergraduate course. In summary, we reached a two-factor construct comprising 26 items on a 5-point Likert scale: (1) Flexible Think- ing and (2) Openness to Feedback, offering a focused yet comprehensive framework for assessing DT education of individuals from diverse disciplines. Furthermore, using our scale through pre- and post-assessment with experimental and control groups, our ANOVA and ANCOVA analyses revealed statistically significant improvements in both factors, with notable gains in Openness to Feedback among DT students compared to the control group.

In the following section, we reflect on the methodology we used for developing this construct, our construct itself, its measured impact, potential applications, and future research opportunities.

### Reflection on the methodology: Meaning-making for exploratory factor analysis with experts

This study's methodological approach combined quantitative and qualitative methods to develop a robust scale and an understanding of the impact of DT education on students from diverse disciplines. Using Exploratory Factor Analysis, we identified two constructs and supplemented this with a focus group session with DT experts who qualitatively evaluated each construct for meaning-making. The final version of the resulting scale comprises 26 items measured on a 5-point Likert scale (Flexible Thinking and Openness to Feedback).

The qualitative component of our research process provided more profound meaning to constructs and established a grounded alignment with the DT stages. In this focus group session, the experts examined each item based on their experiences in the classroom with students. This process facilitated a shared understanding, enabling experts to reach a consensus on item meanings, identify potential themes, and validate each item's alignment with the DT process. Interpreting the results of the exploratory factor analysis by incorporating a qualitative lens helped experts swiftly make meaning out of the findings in a one-hour and 15-min meeting. As a result of the discussions, they agreed on the stages each item fits in the DT process we grounded our curriculum on (Riverdale & IDEO, 2012). Based on these discussions, experts concluded that the.

items under the (Factor 1) Flexible Thinking construct were associated with activities and mindsets in the *interpretation*, *ideation*, and *experimentation* stages. Meanwhile, the items related to (Factor 2) Openness to Feedback were more relevant to the first three stages of the DT process, namely *discovery*, *interpretation*, and *ideation*. (Fig. 6).

Overall, this qualitative approach enriched our study by offering diverse perspec- tives from experts, prompting us to deepen and confirm our findings and refine the final outcomes of the DT scale we contributed. Prior research also highlighted the value of including qualitative approaches (i.e., card-sorting) in the scale development process (Leech et al., 2010; Santos, 2006). Our investigation built upon these previous studies and highlighted the importance of expert focus groups in such processes.

Future studies could, for instance, include pre- and post-course interviews with students to capture their reflections on their creative journey, in addition to the DT experts' perspectives. These reflections could add depth to the survey scores, address- ing limitations associated with purely quantitative, self-reported data. Such research could contribute to developing a rigorous methodology for interpreting the results of a factor analysis using qualitative methods.

## A binary perspective for measuring design thinking impact

Discussions with experts revealed a binary perspective on the mindsets of students engaged in Design Thinking (DT) training. Unlike previous research that categorizes DT skills into multiple dimensions, such as the ten categories proposed by (Vignoli et al., 2023), this study identifies two primary factors: Flexible Thinking, which per- tains to individual capabilities, and Openness to Feedback, which is associated with teamwork and collaboration.

The Flexible Thinking construct captures students' abilities in individual activities, such as embracing various ideas during ideation and applying analytical, construc- tive, and critical thinking. This factor aligns with key DT *mindsets*, including being learning-oriented and practicing critical questioning (Vignoli et al., 2023). It also encompasses *tools* like formulating*"How Might We" (HMW) questions* (Siemon et al., 2018), fostering an adaptive approach to tackling complex problems, and encourag- ing innovative solutions. In psychology, these individual states in teamwork are often characterized by attitudes, values, cognitions, and motivations, such as self-confidence (Marks et al., 2001).

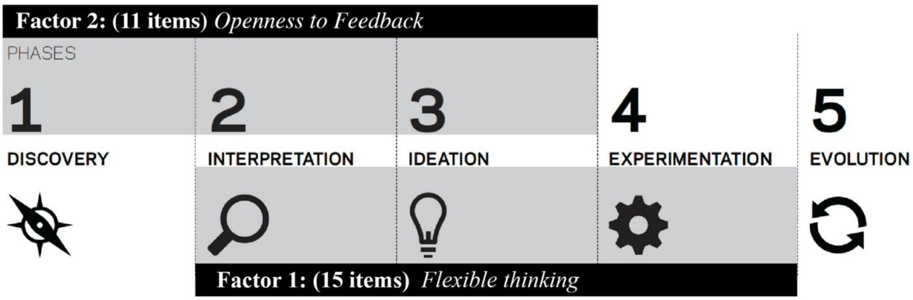



**Fig. 6** Relation between the two factors described in this study and the 5-stage Design Thinking process described in IDEO's' Educator's Toolkit

The Openness to Feedback construct focuses on the skills exhibited by students during group activities. This factor measures collective mindsets through statements related to teamwork, such as prioritizing team success over individual goals and iter- ating on ideas based on feedback from peers or external contributors. Openness to feedback incorporates DT *mindsets* like comfort with ambiguity, collaboration, and risk-taking (Vignoli et al., 2023), as well as abilities of DT *tools* such as sketching and hands-on prototyping (IDEO, 2015). Previous research underscores the importance of both interdependence and team autonomy in fostering positive psychological outcomes in teamwork (Rasmussen & Jeppesen, 2006). Our findings extend this knowledge by demonstrating that the adapted DT course positively influences students' teamwork skills, suggesting an indirect benefit to the psychological states of individuals practicing DT.

By focusing on the individual and collaborative skills of those practicing the DT method, the binary perspective offers a streamlined approach to measuring the impact of DT education. Both factors are vital for DT mindsets and abilities in environments of participants with diverse disciplinary backgrounds and in a collaborative workflow (Kaygan, 2023). Therefore, compared to multi-category scales, the scale provides a simplified yet focused framework, making it easier to assess the development of essen- tial DT mindsets and abilities. However, this focus may result in overlooking other skills identified in previous research (Greene et al., 2019; Trung et al., 2024; Vignoli et al., 2023). To mitigate this limitation, the in-depth theoretical review and the expert interviews informed the initial questionnaire development, ensuring that the selected items effectively covered the core aspects of DT.

The binary perspective focuses on individual and teamwork skills, which opens up opportunities for future research to investigate the factors that may influence these results. For instance, we expect the course participants' multidisciplinary structure could influence the results, yet we did not conduct an analysis to measure its effects. Our curriculum design may also have affected the results by increasing participants' concentration on the projects they were working on, reducing the effects of any other external factors. Further research could investigate how the results are influenced by the duration of the course and the effect of participant backgrounds.

## Applications of design thinking impact measurement scale

According to the ANOVA and ANCOVA tests, the results met our expectations of improved DT skills in both factors after taking this course. While this study concen- trated on an 11-week undergraduate course modeled after IDEO's Educator's toolkit (Riverdale & IDEO, 2012), the impact measurement scale has broader applications beyond the classroom setting. The potential of this research extends to various DT courses in different types of institutions. For instance, this scale can be applied in the creative industries to assess the effectiveness of DT practices. The multidisciplinary composition of these industries, where individuals from diverse professions collaborate on projects, mirrors the study's setting, enhancing the scale's relevance. Despite the promising initial findings, further research is required to validate the scale's applicabil- ity across diverse contexts. Future studies could examine its performance with groups with different degrees of DT expertise, backgrounds, and age groups. Significantly, this curriculum could be adapted to other contexts with varying temporal requirements (shorter and longer-term projects). The potential applications of the scale also encompass broader business settings, particularly for long-term projects that are prevalent in many companies. From the management perspective, assessing the effectiveness of the methodologies employed to facilitate successful business development is essen- tial. Verifying this instrument for such settings could offer project managers a tool to record the progress of their team members, analyze the project process at the end of the project, and promote company workflows. The study's curriculum itself is adapt- able to different time frames and settings, catering to both shorter and longer-term projects. This adaptability underscores the flexibility of the approach and its poten- tial to contribute to DT education and practice across various fields. We are currently in the process of developing a much shorter version of the curriculum and aim to try this new rapid approach with business professionals.

### Limitations

One of the main limitations of this study is the reliance on self-reported data. While self-reported measures are necessary for capturing personal perceptions of growth in areas such as mindsets and abilities, they can also introduce social desirability bias (van de Mortel, 2008), where participants may unintentionally overestimate their progress. This tendency may also have been influenced by students' awareness of the course objectives and expected outcomes, potentially skewing their reported skill develop- ment accuracy. Future research could address this limitation by incorporating multiple measures, including observational methods, to complement self-reported data.

Another important consideration is that our scale focuses on two factors,"Flex- ible Thinking" and"Openness to Feedback." While these are central to the Design Thinking (DT) process, the scale does not individually address other DT mindsets and abilities, as discussed in the previous section. Instead, we interpret these factors as encompassing a broader range of aspects. For example,"Openness to Feedback" includes elements of DT mindsets such as comfort with ambiguity, collaboration, and risk-taking (Vignoli et al., 2023), as well as DT actions like sketching and hands-on prototyping (IDEO, 2015), therefore, independently addressing other DT mindsets and abilities could provide a more comprehensive understanding of the course's impact. Furthermore, future research could administer the scale to a new, independent post-intervention sample and perform a confirmatory factor analysis to test whether the two-factor structure we identified by EFA replicates, thereby strengthening the instrument's validity.

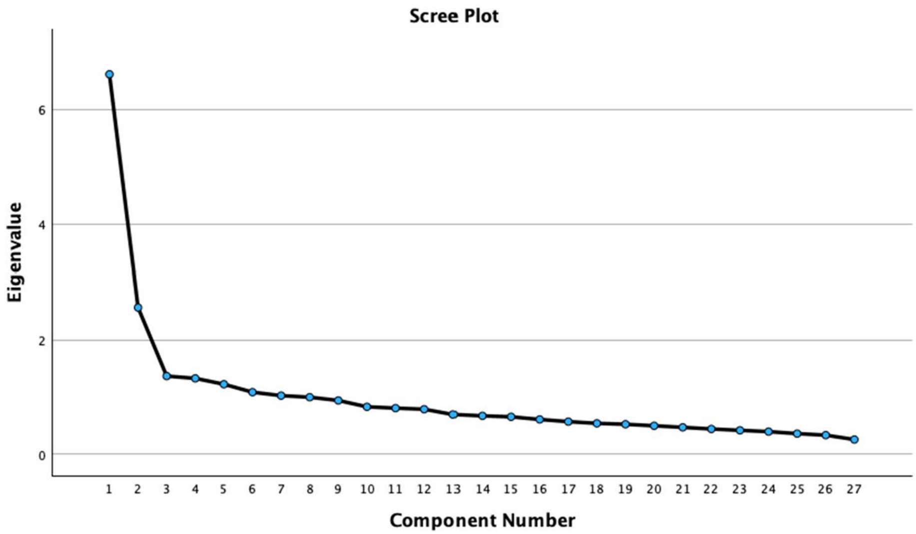
On the other hand, while the study's multidisciplinary student population mir- rors real-world DT contexts, it also introduces complexities. Students from disciplines outside of design might engage with and benefit from DT concepts differently than those from design-related fields (Kaygan, 2023). Future research could investigate the impact of students' disciplinary backgrounds on DT skill development. This would provide insights into which disciplines are more likely to embrace and benefit from DT principles, leading to a more nuanced understanding of DT education in multidisci- plinary settings. By acknowledging and addressing these limitations, future research can contribute to a more refined and comprehensive understanding of the impact of DT education in multidisciplinary contexts, investigate the nuances of disciplinary differences, and ultimately lead to developing more effective and tailored DT curricula.

## Conclusion

Design thinking mindsets and abilities in multidisciplinary environments are highly appreciated for supporting innovative perspectives, creative thinking, and collabora- tive workflows to approach complex problems. Therefore, in this study, we developed a scale for measuring the impact of the Design Thinking (DT) course among novice multidisciplinary participants and validated it with 276 undergraduate students using exploratory factor analysis, resulting in a two-factor solution: (1) Flexible Thinking and (2) Openness to Feedback. Further, using ANOVA and ANCOVA, we revealed the delivered impact in an 11-week structured Design Thinking course. The results from 162 participants (control: 34, experimental: 128) who completed both pre- and post-assessments showed statistically significant increases in students' Design Thinking skills in two factors.

Overall, our contribution is two-fold: (1) a developed and validated scale to mea- sure the impact of DT, (2) interpretation of the resulting two factors through a focus group study with five experts. In a semester-long multidisciplinary setting, we dis- covered that the impact of Design Thinking spreads across two main perspectives of *individual* development in Flexible Thinking and *collaborative* development through Openness to Feedback. To the best of our knowledge, this is the first scale developed to measure the impact of DT mindsets and skills in a multidisciplinary undergradu- ate course in two factors. We believe our work establishes a foundation for developing curricula adaptable to different temporal requirements, catering to both shorter and longer-term projects. In our experiment, modifying the IDEO Toolkit model by replac- ing the maker-lab with video sketching and incorporating a"cryptomnesia-preventing guerrilla thinking task" enabled us to develop a more affordable and universally acces- sible curriculum. This evaluation scale also played a crucial role in facilitating this development process. This adaptability allows for the application of our scale to other multidisciplinary contexts like creative industries, where individuals with diverse occupations work on a singular project.

## Appendix A



## Appendix B: The scale for design thinking mindset and abilities:

Instructions to respondents

Please read each statement and indicate the degree to which it currently describes your ability, using the scale below.

1 = I cannot do this at all 2 = I cannot do it 3 = I am unsure whether I can or cannot 4 = I can do it 5 = I can do it very well.

| # | Item | **1** *I cannot do this at all* | **2** *I cannot do it* | **3** *I am unsure whether I can or cannot* | **4** *I can do it* | **5** *I can do it very well* |
|---|---|---|---|---|---|---|
| 1 | When generating ideas about a topic or problem, I can set aside my previous thoughts and assumptions related to the subject | | | | | |
| 2 | I can generate a large number of alternative ideas about a topic or problem | | | | | |
| 3 | When generating ideas about a topic or problem, I let my imagination roam | | | | | |
| 4 | When generating ideas about a topic or problem, I can think in a systematic manner | | | | | |
| 5 | I find it necessary and meaningful to seek ideas from people relevant to the topic I am addressing (e.g., if working on operating rooms, I would talk to doctors, nurses, or patients) | | | | | |
| 6 | When generating ideas about a topic or problem, I can think beyond the existing solutions | | | | | |
| 7 | I can analyse and interpret the qualitative (non-numerical) information I obtain about the topic I am addressing | | | | | |
| 8 | I am curious and eager to generate as many ideas as possible about a topic or problem | | | | | |
| 9 | I can identify similarities among the different findings I obtain about the topic I am addressing and find connections | | | | | |
| 10 | I know and can use the necessary methods to convey my ideas concisely and efficiently to recipients | | | | | |

| # | Item | **1** *I cannot do this at all* | **2** *I cannot do it* | **3** *I am unsure whether I can or cannot* | **4** *I can do it* | **5** *I can do it very well* |
|---|---|---|---|---|---|---|
| 11 | When conveying my ideas about a topic to others, I prefer to show and experience them (through drawings or tangible models) rather than just explaining | | | | | |
| 12 | I can apply the methods I have found effective on one topic or problem to other everyday situations | | | | | |
| 13 | I am skilled at critiquing the ideas and thoughts of others to help move them to a better point | | | | | |
| 14 | When I start generating ideas about a topic or problem, I tend to reach a clear conclusion quickly | | | | | |
| 15 | I can formulate questions about a topic of interest in a way that allows me to conduct research on it | | | | | |
| 16 | When addressing a topic or problem and presenting multiple solutions, I can objectively eliminate ideas based on set criteria | | | | | |
| 17 | When thinking about a problem, I make an effort to consider not only my own perspective but also those of others | | | | | |
| 18 | When generating ideas about a topic or problem, I tend to think that the first idea that comes to mind is correct | | | | | |
| 19 | When generating ideas about a topic or problem, I continue to think based on the first alternatives that come to mind | | | | | |
| 20 | When addressing a topic or problem, I am curious about others' thoughts and perspectives | | | | | |
| 21 | I am skilled at collaborating with multiple individuals and dividing tasks effectively | | | | | |
| 22 | When I receive negative feedback on my ideas about a topic, I tend to defend them without thinking | | | | | |

| # | Item | **1** *I cannot do this at all* | **2** *I cannot do it* | **3** *I am unsure whether I can or cannot* | **4** *I can do it* | **5** *I can do it very well* |
|---|---|---|---|---|---|---|
| 23 | Before generating ideas about a topic or problem, I conduct research on the subject | | | | | |
| 24 | When working on a topic, I prioritise the success of the team I am part of over my individual success | | | | | |
| 25 | When I receive feedback from someone else on my ideas, creations, or presentations, I immediately start thinking about the negative points | | | | | |
| 26 | When I receive feedback from someone else on my ideas, creations, or presentations, I notice and reflect on the thoughts or concepts my work evokes in the other person | | | | | |

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