Design Science

Measuring design mindset: developing the Design Mindset Inventory through its relationship with ambiguity tolerance, self-efficacy and sensation-seeking

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Abstract

Designers rely on many methods and strategies to create innovative designs. However, design research often overlooks the personality and attitudinal factors influencing method utility and effectiveness. This article defines and operationalizes the construct *design mindset* and introduces the *Design Mindset Inventory* (*D-Mindset0.1*), allowing us to measure and leverage statistical analyses to advance our understanding of its role in design. The inventory's validity and reliability are evaluated by analyzing a large sample of engineering students ($N = 473$). Using factor analysis, we identified four underlying factors of *D-Mindset0.1* related to the theoretical concepts: *Conversation with the Situation*, *Iteration*, *Co-Evolution of Problem–Solution* and *Imagination*. The latter part of the article finds statistical and theoretically meaningful relationships between *design mindset* and the three design-related constructs of *sensation-seeking*, *self-efficacy* and *ambiguity tolerance*. *Ambiguity tolerance* and *self-efficacy* emerge as positively correlated with *design mindset*. *Sensation-seeking*, which is only significantly correlated with subconstructs of *D-Mindset0.1*, is both negatively and positively correlated. These relationships lend validity *D-Mindset0.1* and, by drawing on previously established relationships between the three personality traits and specific behaviors, facilitate further investigations of what its subconstructs capture.

Keywords: Design mindset, Psychometrics, Psychology, Personality trait, Self-efficacy, Ambiguity tolerance, Sensation-seeking

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1. Introduction

Designers' influence on the design process has often been overlooked in design research (Dorst 2008), particularly regarding how personality and attitude influence design activities. One of the exceptions is Daalhuizen *et al.* (2014), who show that differences in mindset influence the experience of using design methods. A strong alignment of mindset and methods is theorized to correlate with productive

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method use and design practice (Daalhuizen 2014), the effective implementation of design methodology (Andreasen 2003; Andreasen *et al.* 2015) and design practices more generally (Wynn and Clarkson 2024).

As the design landscape continues to evolve, and people with more diverse backgrounds and experiences are employing design methodologies in interdisciplinary collaborations and across more and more domains, the significance of understanding how mindset influences actions in the design process becomes even more pronounced. To ensure the successful and effective use of design methodologies, we need to understand how these differences in mindset influence both the use of design methods and collaboration in the design process. To this end, this article introduces the *Design Mindset Inventory* (*D-Mindset0.1*),[1] which represents a foundational step in unraveling the interplay between designers and the design context by enabling the measurement of *design mindset*.

The contribution of this work is twofold. Firstly, based on Crismond and Adams' (2012) *Informed Design Teaching & Learning Matrix*, which structures core design behaviors and strategies, and the broader design theory (e.g., Schön 1983; Cross 1990, 2001; Dorst and Cross 2001; Lawson and Dorst 2009; Ball and Christensen 2019; Wynn and Clarkson 2024), identifying values and beliefs guiding design practices, we develop and offer initial validation of *D-Mindset0.1*. The inventory is a crucial step toward quantifying the core concept of *design mindset*, allowing us, for the first time, to measure and assess it directly. Such an instrument has substantial value for design research, practice and education. For example, it can improve our understanding of students' progression throughout their design education and how different design pedagogies affect the development of *design mindset*. Understanding how differences in *design mindset* influence design practice can furthermore inform tailored strategies that leverage individual strengths and mitigate potential challenges in both design education and practice. Secondly, in relating design mindset to the personality traits of *sensation-seeking*, *self-efficacy* and *ambiguity tolerance*, we deepen our understanding of *design mindset* and place our research in relation to the broader research into these personality traits, thus contributing to both design and psychology research.

2. Background

Generally, mindsets can be construed as the sum of the cognitive activities conducive to successful task performance (Gollwitzer 2012). They constitute the beliefs and attitudes determining how situations are interpreted and understood (Gupta and Govindarajan 2002; Nelson and Stolterman 2012) and, as reflected in the myriads of different mindsets that exist, they often define themselves in reference to a specific attitude or approach, be it cultural or professional (Buchanan 2024).

[1]A preliminary version of this paper and the Design Mindset Inventory (*D-Mindset0*) was published and presented at *the International Conference of Engineering Design* in 2023 (ICED23) (see Lavrsen *et al.* 2023). This paper expands on the conference paper, including all new analyses and evaluations of the inventory, resulting in the updated naming (*D-Mindset0.1*) to distinguish the two versions but also to indicate their close relationship. Additionally, we extend our analysis of the four subconstructs identified in the inventory. Nevertheless, we still consider this version a preliminary inventory needing further development and more empirical data and testing."

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2.1. Design mindset

Building on the above description of mindset and the concept of a *method mindset*, connecting mindset and design practice (see Andreasen 2003; Daalhuizen *et al.* 2014; Andreasen *et al.* 2015), we define *design mindset* as the beliefs and attitudes determining the interpretation and understanding of design situations and the choice of appropriate design activities. As such, *design mindset* goes beyond the mechanistic execution of prescribed methods, delving into how designers interpret, react to and interact with the world, the design challenges they encounter and the design methodology used to guide the activity (Andreasen *et al.* 2015). It encompasses the beliefs, attitudes and cognitive dispositions underpinning a designer's problem-solving approach and creative expression (Lawson 2005; Daalhuizen 2014; Andreasen *et al.* 2015; Wynn and Clarkson 2024). In other words, *design mindset* is the mindset that aligns with effective design practices.

2.2. Measuring design mindset

Several instruments for measuring design (thinking) mindset already exist (e.g., Chesson 2017; Dosi *et al.* 2018). However, these instruments often lack a clear definition of mindset and, as a result, include overlapping constructs at different conceptual levels and varying relevance for design practice.

2.2.1. Components of design mindset

Often, the concept of a *design mindset* has been structured around components like creative thinking, human-centeredness, prototyping, visualization, collaboration, optimism, self-efficacy, curiosity, risk-taking, ambiguity tolerance, empathy, openness, holistic thinking, to mention a few (see Blizzard *et al.* 2015; Howard *et al.* 2015; Schweitzer *et al.* 2016; Chesson 2017; Dosi *et al.* 2018). While each of these might help inform design practices, they do so on different levels and often in overlapping ways, making it hard to define, structure or distinguish between them. For example, Schweitzer *et al.* (2016) connect empathy with human-centeredness, collaboration and, more broadly, including different perspectives in the design process, thus hinting at a connection to holistic thinking. Schweitzer *et al.* (2016) also classify several of these components as mindsets in their own right, suggesting that design (thinking) mindset is not one construct but multiple. This is also reflected by several of these components being well-established constructs outside design research with their own measurement scales – e.g., empathy, optimism, self-efficacy and ambiguity tolerance. While not necessarily measuring these constructs in a design-specific context (Chesson 2017), it indicates these are not unique to designers and design practice. When Chesson (2017) then defines a design thinker as"…an individual that uses all of these capabilities in their approach to problem solving" (p. 57), it reduces *design mindset* to generic characteristics potentially unrelated to design practices, skills and expertise. For example, being empathic or tolerant of ambiguity does not necessarily make one a good designer. It is conceivable that somebody could embody all of these attributes while only showing limited design capabilities or knowledge. They might have potential as designers, but merely embodying these capabilities does not translate into design expertise. Furthermore, this elevates components like human-centeredness and collaborations to a defining aspect of being a designer, despite both being context-dependent and far from

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appropriate in all design situations. In the case of human-centeredness, we even see a transition toward, for example, planet-centered design, including a significantly broader perspective of what is central in the design process, indicating that human-centeredness is not an indisputable element of designing but perhaps more of a guiding principle that changes in response to the designer's values and the specific design problem. Including such related constructs in a measure of *design mindset* limits our ability to explore and understand how they relate to and influence attitudes toward core design practices and strategies.

2.2.2. Mindset and behaviors

In a similar vein, most of the existing instruments for measuring *design mindset* tend to extrapolate mindset based on self-assessment of design-related behaviors rather than the underlying beliefs and attitudes at the core of mindset. For example, a majority of the items in both Chesson's (2017) and Dosi *et al.*'s (2018) inventories are about how people act/react in certain situations and do not directly represent the values and beliefs guiding the behavior or assessment of appropriateness in the situation.

Schweitzer *et al.* (2016) recognize this lack of distinction between "…cognitive (thinking) and behavioural (doing) and affective (feeling) components…" (p. 6) in their description of design thinking mindset, even suggesting it is impossible to separate them. However, conflating mindsets and behaviors is problematic since different mindsets might prompt similar behaviors in certain situations, making it hard to identify the underlying values. While mindset informs behaviors, assessing mindset based on specific behavioral responses runs the risk of missing the underlying values guiding these responses.

Consequently, when measuring *design mindset*, the instrument should not aim at capturing specific behavioral patterns but rather the underlying values driving these. By capturing the underlying values and attitudes related to design practice, such an instrument can potentially facilitate the investigation of specific design behaviors as they relate to *design mindset.*

2.3. A Differentiation between the design mindset and personality traits

By distinguishing between design-specific values and attitudes, i.e., *design mindset*, and the more general constructs, characteristics and behaviors often associated with design, we aim to develop a measurement instrument capturing only essential values related to design practice. The approach allows us to start understanding these core values and attitudes separate from related and overlapping constructs.

In this article, we specifically utilize the three constructs *sensation-seeking*, *self-efficacy* and *ambiguity tolerance* to further our understanding of *design mindset* and its subconstructs. Going forward, we refer to these three constructs as *personality traits* to distinguish between *design mindset* and these more generic constructs and to indicate that they are generally considered more stable than we consider design mindset to be.

The three personality traits are all well-established within the psychology literature and have been associated with design-related characteristics such as openness to new experiences, confidence in influencing the world around them and a preference for complexity (Zuckerman 1979; Bandura 1997; Dosi *et al.* 2018;

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Mahmoud *et al.* 2020). Though distinct, these constructs share underlying threads that interweave their influences within the design process. They contribute to a designer's cognitive approach to design challenges, affecting their willingness to explore unconventional solutions, attention to detail, collaboration with others and capacity to manage the emotional highs and lows of the creative journey.

In the development of *D-Mindset0.1*, we use the established relationships between the three personality traits and design and/or creativity to strengthen the argument for overall construct validity. Furthermore, investigating the relationship between the three personality traits and the subconstructs of *D-Mindset0.1* helps us make sense of the latter.

2.3.1. Self-efficacy

Self-efficacy is not a generalized trait but rather a context-specific assessment of one's competence. In the context of design, *self-efficacy* has been linked to the more domain-specific constructs of *Creative confidence* within *design thinking* (see Jobst *et al.* 2012; Kelley & Kelley 2013) and the more general *Creative self-efficacy* (see Beghetto 2020).

The construct of *self-efficacy* was introduced by Bandura (1977) and refers to an individual's belief in their ability to successfully perform specific tasks, achieve goals and overcome challenges in various domains of life. As such, *self-efficacy* influences how people interpret situations and their motivation for engaging in them. Bandura (1977, 1997) states that *self-efficacy* plays a crucial role in shaping behavior, influencing people's choices, the effort they invest and their persistence in the face of obstacles. He goes as far as to say that "…an unshakable sense of efficacy…" (p. 239) is required to persevere in creative endeavors where progress is slow, outcomes uncertain and innovative solutions might be devalued if they challenge existing norms and values (Bandura 1997). In other words, designers' level of *self-efficacy* can significantly impact their approach to these challenges. People with high *self-efficacy* are likelier to exhibit proactive behaviors, set ambitious goals, invest effort and persist in the face of setbacks (Bandura 1997). A belief in one's capability to manage uncertainty and surmount obstacles fosters a willingness to engage with ambiguity, explore new design strategies, experiment with unconventional ideas and adapt to evolving requirements of working iteratively on solving complex problems.

2.3.2. Ambiguity tolerance

Tolerance for ambiguity is "…the tendency to perceive ambiguous situations as desirable" (Budner 1962, p. 29), where *ambiguous situations* refer to situations "which cannot be adequately structured or categorized by the individual because of the lack of sufficient cues" (Budner 1962, p. 30). Most design problems are wicked problems with no clear solutions and multiple stakeholders; thus, most design situations resemble ambiguous situations (Mahmoud *et al.* 2020). Therefore, dealing with ambiguity is also closely related to design practice. Cross (1990, p. 130) identified: "[to] tolerate uncertainty, [and] working with incomplete information" as a significant aspect of what designers do – an observation that has been repeated plenty of times since (Lawson and Dorst 2009; Hassi and Laakso 2011; Dosi *et al.* 2018; Mahmoud *et al.* 2020). Similarly, *reflection in action*, a core concept of professional practice and central to our understanding of designing, is a

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response to the vague, uncertain and ambiguous problems of practice (see Schön 2017). Furthermore, Cash and Kreye (2017) and Ball and Christensen (2019) highlight uncertainty reduction as one of the primary motivators for design activities.

Ambiguity tolerance lets designers embrace uncertainty, stay open to alternatives and defer judgment (Mahmoud *et al.* 2020). Herman *et al.* (2010) even state that high *ambiguity tolerance* might facilitate the unfreezing of *mental models* by letting people engage more intensely with a situation, pushing new learning and, thus, potentially new framing of a situation. In this way, *ambiguity tolerance* is also related to divergent thinking and the exploration of the design problem and solution.

On the other hand, low tolerance for ambiguity is associated with a "tendency to view ambiguous situations rigidly in black or white" (Rosen *et al.* 2014, p. 62), rejection and avoidance of such situations and emotional reactions such as uneasiness, discomfort, dislike, anger and anxiety (Rosen *et al.* 2014). This is associated with a fixed mindset that potentially can lock designers in their way of designing and using methods, even if the context requires other approaches. Furthermore, a low tolerance for ambiguity could result in an overreliance on convergent thinking, reducing opportunity space and limiting the potential for creative problem-framing and finding innovative solutions. In other words, the aversion to ambiguity might lead to *satisficing* and reliance on the first adequate solution that comes to mind rather than a more creative or optimal one (Simon 1996; Bandura 1997; Runco 2014).

2.3.3. Sensation-seeking

Sensation-seeking is a well-established psychological construct dating back to the 1960s. It is the inclination to seek diverse, novel, complex and intense sensory and experiential stimuli, often involving a willingness to undertake physical, social, legal and financial risks to attain such experiences (Zuckerman 1979, 1994). *Sensation-seeking* has a deep-rooted and well-established connection to risk-taking (Zuckerman 1979, 1994; Hoyle *et al.* 2002). People scoring high in *sensation-seeking* are likelier to engage in risky behaviors (Zuckerman and Aluja 2015); they tend to underestimate the risk associated with their behaviors and are more likely to repeat them (Hoyle *et al.* 2002).

Risk-taking, not fearing failure or the willingness to fail in order to learn, is crucial for creativity (Hennessey and Amabile 2010). There is always an element of risk associated with any creative endeavor (Runco 2014). Creativity, by definition, requires novelty (Weisberg 2009; Hennessey and Amabile 2010). Regardless of the level of novelty, creating something new is creating something untested. It forces designers into uncharted territory where repeated failures and boundary-pushing are commonplace before finding an appropriate solution. In line with this, a correlation between *sensation-seeking* and *ambiguity tolerance* has been observed (Zuckerman 1979). Similar to both *self-efficacy* and *ambiguity tolerance*, a high level of *sensation-seeking* leads designers to explore the new and unknown. Sensation seekers' inherent desire for variety pushes them toward openness to new experiences and perspectives (Franken 2002; Hoyle *et al.* 2002). Their willingness to take risks lets them go against norms and challenge the status quo (Zuckerman and Aluja 2015). This inclination toward novelty and the uncharted

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complements *divergent thinking*, which involves breaking away from conventional thought patterns to produce a multitude of unique ideas. The correlation between *sensation-seeking* and both openness and divergent thinking has been empirically supported (Zuckerman 1979; McCrae 1987) and suggests that high sensation seekers are more inclined to find creative solutions to problems.

3. Method

To realize the goals of this article, we first develop an inventory to measure *design mindset* by operationalizing conceptualizations from existing design theories about informed designers' strategies and behaviors. This process includes constructing items that capture the values and beliefs underlying such behavioral traits (see Section 4). Following the guidelines for developing assessment instruments (see Abell *et al.* 2009), we then refined the items through testing and expert feedback, assessing their reliability, validity and alignment with established theoretical frameworks.

We conducted exploratory factor analyses (Watkins 2018) to reveal the factorial structure of *D-Mindset0.1*, revealing four underlying factors (see Section 5). Drawing on design theory, we then recontextualize the items and name the four subconstructs of *D-Mindset0.1* (see Section 6).

Equipped with the initial inventory, we then explore the relationships between *design mindset* and the three personality traits: *ambiguity tolerance*, *self-efficacy* and *sensation-seeking* (see Section 7). These three personality traits have all been connected to creativity and behaviors central to design and can, as such, provide further evidence for the overall construct validity and support for our framing of the subconstructs. We use stepwise multiple linear regression analyses to explore the relationship and uncover the extent to which *design mindset* is associated with these personality traits.

To assess the validity of *D-Mindset0.1*, an independent sample *t*-test was conducted to establish its sensitivity to measure differences in the average *D-Mindset0.1-scores* between two subgroups of the sample with known differences in levels of design education (see Section 8.1). McDonald's Omega (ω) was calculated to determine the internal consistency of *D-Mindset0.1* and its underlying factors (see Section 8.2).

A more detailed description of how the methods are used follows in the subsequent sections describing each stage in the inventory's development process.

3.1. Data collection

All data was collected through a 60-item questionnaire (see Appendix A), which was administered as part of the course Innovation in Engineering at the Technical University of Denmark (DTU), employing the software SoSci Survey (see Leiner 2019). The students were required to fill in the questionnaire as part of the course but had the option not to have their data used for the study.

The questionnaire consisted of four main parts, defined by the items making up the inventories for measuring *design mindset*, *self-efficacy*, *ambiguity tolerance* and *sensation-seeking*. Besides *D-Mindset0.1* introduced in this article, we utilized the General Self-Efficacy Scale (GSES) (Schwarzer & Jerusalem 1995), the Tolerance for Ambiguity Scale (TAS) (Herman *et al.* 2010) and the Brief Sensation Seeking

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Scale (BSSS) (Hoyle *et al.* 2002) to measure each construct, respectively. To fit the format of the other inventories and increase the questionnaire's usability, we adapted the GSES from a 5-point to a 7-point Likert scale. In addition to the four inventories, the questionnaire included items related to consenting to participate, demographic information and experience.

3.2. Participants

We recruited the participants for this study among 586 engineering students enrolled in the master's course Innovation in Engineering at DTU. Out of the 586 students in the course, 473 completed the questionnaire (response rate: 87%). Of the sample, 298 (63%) individuals identified as male, while 171 (36%) identified as female. Additionally, two participants (<1%) chose the category "other", and two participants did not provide an answer. The age range was 20–41 years, with an average age of 24.5 years ($SD = 2.4$), and the cohort encompassed a diverse range of educational backgrounds, spanning over 30 distinct engineering specializations (see Appendix B). While being a sample of convenience, based on the diversity of disciplinary specializations, varying levels of practical experience ($M = 4.3$ months, $Md = 0$, $SD = 10.9$) and exposure to design and innovation theory ($M = 1.7$ courses, $Md = 1$, $SD = 2.43$), we consider the sample to be representative of engineering students.

3.3. Data processing

Before conducting the analyses, the data was cleaned. Twenty entries without data or with only demographic data were removed before the analyses. All analyses were done using JASP (JASP Team 2023).

Following Kim's (2013) guidelines for the assessment of distribution, we conclude that our data generally falls within normality. The only exception is the scores for the subconstruct of *Conversation with the Situation.* However, considering the large sample size, we assess the analyses to be robust enough to handle this deviation.

4. Operationalizing design mindset

At the core of operationalization is the inference of unobservable phenomena from observations and theory (Abell *et al.* 2009). As the only directly observable aspect of *design mindset*, the observed behaviors of designers are a great starting point for inferring design values and beliefs. Therefore, we build on Crismond and Adams' (2012) *Informed Design Teaching & Learning Matrix* to operationalize *design mindset.* It provides a structured overview of design behaviors. Furthermore, by distinguishing between naïve and so-called 'informed designers,' Crismond and Adams' (2012) matrix highlights the difference in the underlying values of the behavioral patterns between the two levels of expertise.

4.1. Generating inventory items

Crismond and Adams (2012) define nine design strategies representing core behavioral patterns displayed by designers (see Figure 1). Based on these design

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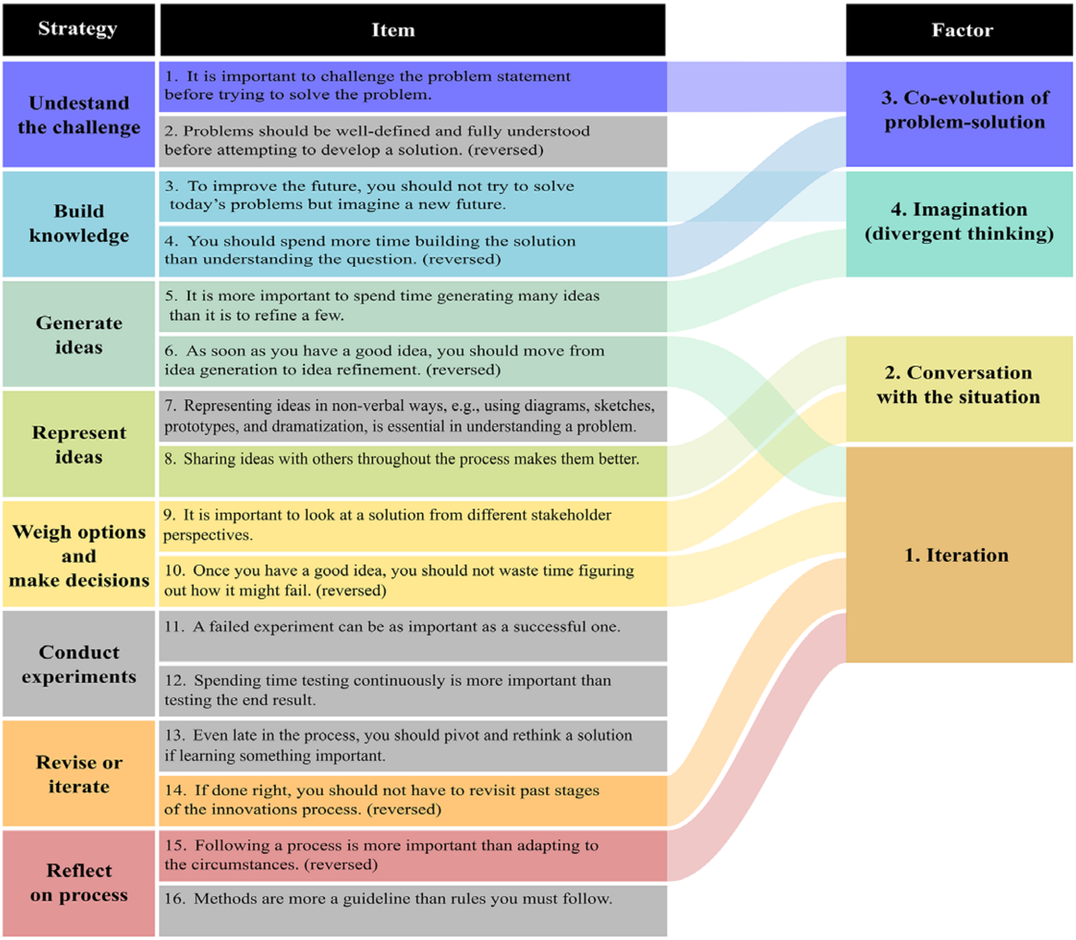

Figure 1. Evolution of the Design Mindset Inventory.

strategies and contrasting behavioral patterns, the first author generated a list of proto-items formulated as statements related to attitudes toward the strategies and associated behaviors. To avoid conflating mindset and behavior, we opted for a format of agreement-to-value statements rather than behavioral self-assessments in formulating the items for *D-Mindset0.1*. Combined with using a universal 7-point Likert scale – ranging from *strongly disagree* (=1) to *strongly agree* (=7) – as response format, this allows us to measure how much the respondent values the strategies presented in each item. Using the Likert scale also helps improve the sensitivity and reliability of the inventory (Abell *et al.* 2009).

4.2. Refinement of inventory items

The proto-items evolved through an iterative process of feedback and refinement. The second and third authors acted as experts, providing feedback on the proto-items regarding relevance, fit to the design strategies, the broader design theory, readability and concept clarity.

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As we converged on an acceptable list of proto-items, two for each design strategy – except *Troubleshoot* – were selected to keep the inventory short for ease of use. We excluded *Troubleshoot* due to an overlap with other strategies, its more general nature (non-design-specific) and little mention of it as a separate design capability in the design literature. In Lavrsen *et al.* (2023), we go deeper into the reasoning behind each item in relation to the strategies identified by Crismond and Adams (2012).

The selected items were then evaluated by teaching assistants for the course, who had a similar profile as the target population, prompting new iterations of refinement. Figure 1 contains the resulting list of items.

5. Finetuning the inventory

We conducted an exploratory factor analysis to validate and explore the factors underlying *D-Mindset0.1* as measured through our inventory, following Watkins (2018). Through this analysis, we aim to develop and finetune the inventory further to increase its reliability.

A Bartlett test (Bartlett 1954) revealed a significant chi-square value ($p < 0.001$), indicating the factorability of the inventory (Watkins 2018). This was supported by the Kaiser–Meyer–Olkin (KMO; Kaiser 1974) measure of sampling adequacy (MSA = 0.751), which is above the desired threshold of 0.7 (Watkins 2018). These statistical indicators affirm the suitability of conducting an exploratory factor analysis concerning the present dataset.

We employed explorative factor analysis with an oblique rotation using the Promax criterion, which allows factors to be correlated to reveal the factorial structure underlying *D-Mindset0.1* (see Table 1). To ascertain the optimal number of factors to include in the inventory, we applied a factor analysis-based parallel analysis, comparing the observed eigenvalues from the factor analysis to those generated from random datasets. A factor loading of 0.4 was set as a threshold for including items into factors in the model.

Initial analysis revealed a negative correlation between Item 2 and the rest of the items in the inventory (see Lavrsen *et al.* 2023). We believe the negative correlation is due to a suboptimal formulation of the item, resulting in participants agreeing that, ideally, the problem should be fully understood before trying to solve it rather than the intended sentiment: that wicked problems by their very nature only can be fully understood in relation to and by exploring potential solutions. Even though problems ideally should be fully understood before solving them is attempted, this is rarely a viable option for design problems and, therefore, aligns poorly with a *design mindset*. Consequently, to secure a coherent representation of the construct and the internal consistency of the inventory, Item 2 has been excluded from the factor analysis.

The explorative factor analysis shows the items to load into four factors (see Figure 1), accounting for a cumulative proportion of 29.8% of the total variance. Factor 1 explained 9.2% of the variance, Factor 2 9.1%, Factor 3 6.2% and Factor 4 5.3%. The cumulative proportion of variance tells us the extent to which the identified factors explain the variability in the data. In Table 1, the factor loadings are ordered according to factor size. Factor load tells us how strongly the items are related to the factor. The closer to 1 or −1, the closer the connection. *Uniqueness*

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Table 1. Exploratory factor analysis with items assigned to different factors and ordered with decreasing factor loads

Item		Factor 1	Factor 2	Factor 3	Factor 4	Uniqueness
15	Following a process is more important than adapting to the circumstances. (reversed)	0.687				0.526
06	As soon as you have a good idea, you should move from idea generation to idea refinement. (reversed)	0.559				0.719
10	Once you have a good idea, you should not waste time figuring out how it might fail. (reversed)	0.521				0.688
14	If done right, you should not have to revisit past stages of the innovation process. (reversed)	0.470				0.717
08	Sharing ideas with others throughout the process makes them better.		0.945			0.315
09	It is important to look at a solution from different stakeholder perspectives.		0.493			0.566
04	You should spend more time building the solution than understanding the question. (reversed)			0.450		0.777
01	It is important to challenge the problem statement before trying to solve the problem.			0.426		0.773
05	It is more important to spend time generating many ideas than it is to refine a few.				0.515	0.727
03	To improve the future, you should not try to solve today's problems but imagine a new future.				0.487	0.788
07	Representing ideas in non-verbal ways, e.g., using diagrams, sketches, prototypes and dramatization, is essential in understanding a problem.					0.681
11	A failed experiment can be as important as a successful one.					0.789
12	Spending time testing continuously is more important than testing the end result.					0.865
13	Even late in the process, you should pivot and rethink a solution if learning something important.					0.689
16	Methods are more guidelines than rules you must follow.					0.907

Note. The applied rotation method is Promax.

indicates the variance of the item not accounted for by the factors. The higher the *Uniqueness*, the less overlap there is with other items and factors.

The factor analysis also shows that Items 7, 11, 12, 13 and 16 had insufficient loadings to be included in any of the factors and can, therefore, also be excluded from the inventory, leaving us with 10 items in *D-Mindset0.1*.

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6. Interpreting the four factors

The factor analysis revealed an underlying structure of four factors and combined inventory items significantly different from the groupings based on Crismond and Adams' (2012) matrix (see Figure 1). Building on the theoretical underpinnings and our intentions with each item, we named the subconstruct of *D-Mindset0.1* by identifying design theories with the potential to explain these new combinations of items. In the following sections, we describe our interpretations and the theoretical underpinnings of each construct – *Iteration, Conversation with the Situation, Co-Evolution of Problem–Solution* and *Imagination* – arguing for the naming of each.

6.1. Factor 1: iteration

Factor 1 combines items from the strategies: *Generate Ideas*, *Weigh Options and Make Decisions*, *Revise or Iterate* and *Reflect on Process* (see Figure 1). Implicit in all four items is an element of attitude toward the process: should you follow procedures and move on, or continuously iterate and revisit earlier stages? These items have a common denominator: the importance of iteration throughout the design process to address wicked problems. To be effective, designers continuously reflect on their processes and methods, adapting to their circumstances. There are learning opportunities throughout the design process. Working iteratively, revisiting earlier stages and revising earlier decisions is how designers implement learning. Overall, we interpret this cluster of items as allowing feedback loops at both the idea and process levels, serving the co-evolutionary nature of designing (see Dorst and Cross 2001), and have, therefore, named it *Iteration.*

6.2. Factor 2: conversation with the situation

Factor 2 consists of items from the strategy *Represent Ideas* and one from *Weigh Options and Make Decisions* (see Figure 1). These items have a common denominator: they are about sharing ideas with the purpose of viewing them from different perspectives. We interpret this in relation to the concept of *Conversation with the Situation* (Schön 1983). In this view, design is a situated phenomenon (Schön 1983; Simon 1996; Daalhuizen 2014) in which the externalization of ideas plays a central role (Schön 1983; Cross 2001; Dove *et al.* 2018). Moving ideas into the physical world means that the designer and others can interact with them; it makes assumptions explicit and facilitates communication. In interacting with the world, these manifestations reveal their intended and unintended consequences from a multitude of (stakeholder) perspectives, thus providing the designer with feedback for evaluating their actions and understanding of the context (Schön 1983). Together, these re-combined items (see Figure 1) indicate a willingness to engage with the situation by actively sharing one's own ideas and inviting others' ideas and viewpoints into the design process, engaging both team members and stakeholders in a dialogue.

6.3. Factor 3: co-evolution of problem–solution

Factor 3 consists of Items 1 and 4 of *D-Mindset0.1* and combines items from the strategies *Understand the Challenge* and *Build Knowledge* (see Figure 1). Both items

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are related to the problem space and its relation to the solution. We, therefore, interpret this factor as an expression of *Co-Evolution of Problem–Solution*, which underlies the process of framing and reframing (Dorst and Cross 2001). The co-evolution of the problem and solution space is central to design practice (Dorst and Cross 2001; Crilly 2021). Letting the understanding of the problem co-evolve with the solution enables the designer to suspend the decision on a solution (Crismond and Adams 2012), learning through experimentation, reducing assumptions and refining the understanding of the problem and what constitutes an appropriate solution (see Dorst and Cross 2001; Dorst 2015).

6.4. Factor 4: imagination

Factor 4 combines Item 3 from the strategies *Build Knowledge* and Item 5 from *Generate Ideas* (see Figure 1). *Imagination* is one possible framing, encompassing both hypothetical thinking (Item 3) and generating ideas (Item 5). *Brainstorming* was, for example, originally framed as applied imagination (Osborn 1963). Further, *imagination* highlights the creativity involved in hypothetical thinking. To go beyond the apparent or existing and into the realm of innovation, we need to be able to imagine new realities. Central to this is the transition from the concrete to the abstract, an ability related to associative thinking, which is central to stimulating idea generation. However, hypothetical thinking theory tells us that the cognitive process of evaluating hypothetical possibilities is not optimized to find the best but rather a satisfactory path forward (Evans *et al.* 2005). Cash *et al.* (2019) relate this cognitive bias toward *satisficing* to fixation and getting stuck with one often local analogy, hindering imagination and divergent thinking. The combination of the two items could hint at designers' ability to apply imagination productively.

7. Assessing design mindset and its subconstructs through regression analyses

We conducted five stepwise multiple linear regression analyses to help us validate *design mindset* as a construct and understand the nature of its subconstruct. Stepwise regression analyses identify what combination of the independent variables best predicts outcomes in the dependent variable and generate models showing how the variables are related. We used forward selection, with the entry criteria $p < 0.05$ and removal criteria $p > 0.1$. As the construct under investigation, *design mindset* and its subconstructs functioned as dependent variables. *Ambiguity tolerance*, *self-efficacy* and *sensation-seeking* were chosen as the independent variables. As well-established constructs within psychology connected to creativity, design or both, investigating their relationships with *design mindset* sheds light on the construct and provides a more robust theoretical basis for assessing the nature of the subconstructs. The relationships are presented visually in Figure 2. There were no significant multicollinearity issues among the independent variables in any of the models (VIF < 10), and the analysis is therefore omitted from the results below. The descriptive statistics for the three independent and the five dependent variables are presented in Table 2.

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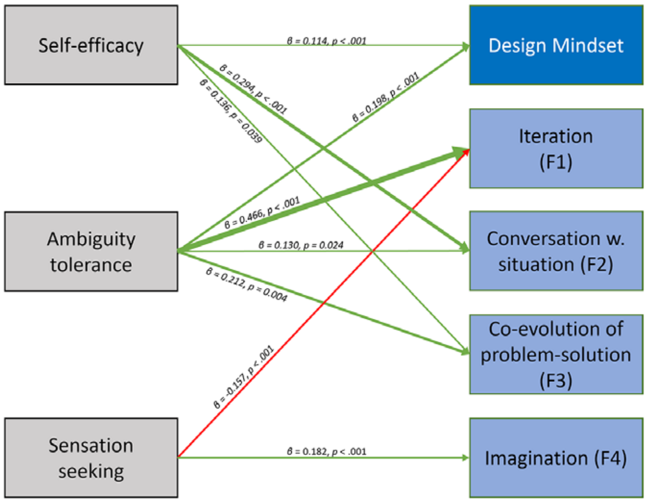

Figure 2. Relationship between independent and dependent variables.

Table 2. Descriptive statistics

Variable	*N*	*N* (missing)	*M*	*SD*
Self-efficacy	473	0	5.18	0.7
Sensation-seeking	473	0	4.35	1.2
Ambiguity tolerance	473	0	4.46	0.6
Design mindset	473	0	4.41	0.5
Iteration (F1)	473	0	4.75	1.0
Conversation with the Situation (F2)	473	0	6.03	0.8
Co-Evolution of Problem–Solution (F3)	473	0	4.97	1.0
Imagination (F4)	473	0	3.74	1.1

7.1. Design mindset

The first of the five regression analyses explores the relationship between the three personality traits and the overall construct of *design mindset* (see Tables 3, 4 and 5). Based on the established relationships between the three personality traits and design practice, or creativity more generally, we expected to find a positive correlation between the overall construct of *design mindset* and the three personality traits.

The final model resulting from the stepwise regression analysis includes *self-efficacy* and *ambiguity tolerance* (see Table 5). The model is statistically significant ($F(2, 470) = 26.5$, $p < .001$; see Table 4). The R-squared value indicates that the included independent variables in Model 3 can explain 10.1% of the variability in *D-Mindset0.1-* scores (see Table 3). Both *ambiguity tolerance* ($b = 0.198$, $p < .001$) and *self-efficacy* ($b = 0.114$, $p < .001$) had a significant positive correlation with *design mindset* (see Table 5), in line with our predictions. The coefficients (b) tell us

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Table 3. Model Summary – Design mindset

Model	R	R^2	Adjusted R^2	RMSE	R^2 change	F change	$df1$	$df2$	p
1			0.000	0.530	0.000		0	472	
2	0.282	0.079	0.077	0.509	0.079	40.600	1	471	< .001
3	0.318	0.101	0.097	0.503	0.022	11.411	1	470	< .001

Table 4. ANOVA – Design mindset

Model		Sum of squares	df	Mean square	F	p
2	Regression	10.5	1	10.5	40.6	< .001
	Residual	122.0	471	0.3		
	Total	132.5	472			
3	Regression	13.4	2	6.7	26.5	< .001
	Residual	119.1	470	0.3		
	Total	132.5	472			

Note. The intercept model is omitted, as no meaningful information can be shown.

Table 5. Coefficients – Design mindset.

Model		Unstandardized (b)	SE	Standardized (β)	t	p	95% CI Lower	95% CI Upper
1	(Intercept)	4.407	0.024		180.916	< .001	4.359	4.455
2	(Intercept)	3.369	0.165		20.462	< .001	3.045	3.69
	Ambiguity tolerance	0.233	0.037	0.282	6.372	< .001	0.161	0.31
3	(Intercept)	2.936	0.207		14.168	< .001	2.529	3.34
	Ambiguity tolerance	0.198	0.038	0.239	5.253	< .001	0.124	0.27
	Self-efficacy	0.114	0.034	0.154	3.378	< .001	0.048	0.18

Note. The following covariate was considered but not included: Sensation-seeking.

that each time scores in *ambiguity tolerance* or *self-efficacy* increase by one, *D-Mindset0.1-* scores increase by 0.198 or 0.114, respectively. These results indicate that the values and beliefs of *design mindset*, to some degree, align with these more general personality traits and, thus, lend credence to the construct validity.

However, we also see that *sensation-seeking* is not included in the final regression model despite its association with divergent thinking and risk-taking. Not being included shows that *sensation-seeking* does not add significant predictive power to the model and, thus, *design mindset* as a whole. This might reflect the less direct relationship between *sensation-seeking* and *design mindset*, relying on a

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Table 6. Model Summary for Factor 1: Iteration

Model	R	R^2	Adjusted R^2	RMSE	R^2 Change	F Change	$df1$	$df2$	p
1			0.000	1.004	0.000		0	472	
2	0.204	0.042	0.040	0.984	0.042	20.415	1	471	< .001
3	0.261	0.068	0.064	0.971	0.027	13.533	1	470	< .001

shared connection to risk-taking and curiosity. That is, however, not to say that *sensation-seeking* is insignificant in understanding *design mindset*, as we shall see in the following sections.

7.2. Factor 1: iteration

Having initially framed and named the four subconstructs of *D-Mindset0.1* is not to say we understand them and what they truly capture. Analyzing the relationship between *design mindset* and the three personality traits, we hope to identify patterns that can enlighten the nature of these subconstructs and, as such, support further development of the inventory and theory-building.

The regression analysis of the relationship between the subconstruct Factor 1 and the three personality traits resulted in a significant regression model ($F(2, 470) = 17.3$, $p < .001$; see Table 7). *Ambiguity tolerance* was positively associated with individuals' scores on this factor ($b = 0.466$, $p < .001$; see Table 8), indicating that students with higher *ambiguity tolerance* scores tended to agree more with the items valuing iterative behaviors. *Sensation-seeking* also influences this factor significantly; however, its relationship is negative ($b = -0.157$, $p < .001$; see Table 8), indicating that high scores in *sensation-seeking* clash with Factor 1. These results make theoretical sense in relation to our framing of Factor 1 as capturing something in relation to *Iteration*.

Ambiguity seems to be a prerequisite for working iteratively. The need for working iterative is, to some extent, a recognition of the ambiguity of a situation. The tendency to view the world in black and white, which characterizes people scoring low in *ambiguity tolerance* (Rosen *et al.* 2014), indicates either an unawareness or active ignorance of the potential ambiguity of a situation. Ignoring a

Table 7. ANOVA – Iteration

Model		Sum of squares	df	Mean square	F	p
2	Regression	19.9	1	19.8	20.4	< .001
	Residual	456.0	471	1.0		
	Total	475.8	472			
3	Regression	32.5	2	16.3	17.3	< .001
	Residual	443.2	470	0.9		
	Total	475.8	472			

Note. The intercept model is omitted, as no meaningful information can be shown.

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Table 8. Coefficients – Iteration

Model		Unstandardized (*b*)	SE	Standardized (*β*)	*t*	*p*	95% CI Lower	95% CI Upper
1	(Intercept)	4.748	0.046		102.852	< .001	4.66	4.84
2	(Intercept)	3.324	0.318		10.443	< .001	2.70	3.95
	Ambiguity tolerance	0.319	0.071	0.204	4.518	< .001	0.18	0.458
3	(Intercept)	3.353	0.314		10.670	< .001	2.75	3.97
	Ambiguity tolerance	0.466	0.080	0.297	5.800	< .001	0.31	0.62
	Sensation-seeking	−0.157	0.043	−0.189	−3.679	< .001	−0.24	−0.07

Note. The following covariate was considered but not included: Self-efficacy.

situation's ambiguity, the primary motivation for iterating disappears (see Cash *et al.* 2023). On the other hand, the higher tolerance for ambiguity allows people to stay in the divergent phase for longer, allowing more information and ideas to come into play. The willingness to keep options open and accept and adapt to changes in the process likewise lets people backtrack the process to explore different opportunities more in-depth. Unsurprisingly, these traits translate into a positive attitude toward working iteratively.

The negative correlation between *sensation-seeking* and Factor 1 might be due to a general aversion toward repeating activities, as that might be perceived as boring. Sensation seekers want variety and change (Franken 2002), which aligns poorly with the perceived repetitiveness of iteration and might explain why they do not wish to repeat or even linger in one stage of the design process.

Another way to interpret the negative correlation between *sensation-seeking* and Factor 1 is concerning risk-taking. A preference for working iteratively could be seen as an expression of limiting risk. Working iterative helps integrate learning into the problem-solving process, thus reducing the uncertainty and the risk of committing to a solution. In other words, people scoring high on *sensation-seeking* might be likelier to take the chance on a wild, unsupported and untested idea. On the other hand, people scoring lower might instead utilize iterations to generate a more substantiated and validated idea before progressing in the design process.

This perspective could also indicate an interesting relationship between *ambiguity tolerance* and *sensation-seeking* in relation to working iteratively. *Ambiguity tolerance* might influence whether a situation is interpreted as threatening (Rosen *et al.* 2014) and thus the risk associated with engaging with it. If this is the case, individuals with high *ambiguity tolerance* might perceive a situation as less risky, meaning that even if they are relatively low-scoring in *sensation-seeking*, they might deem working iteratively unnecessary, thus strengthening the negative effect of *sensation-seeking* on working iteratively. In other words, *ambiguity tolerance* and *sensation-seeking* might moderate the impact of one another on Factor 1. While outside the scope of this article, this relationship could be worth investigating further.

The relationship between *sensation-seeking*, *ambiguity tolerance* and *design mindset* points toward the diverse and sometimes conflicting behaviors associated

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with design in the design literature, where both working iteratively and taking risks are praised (Grocott *et al.* 2019; Carlson *et al.* 2020).

This regression model explained 6.8% of the variance in scores of *Iteration* in *D-Mindset0.1* (see Table 6).

7.3. Factor 2: conversation with the situation

The regression analysis for *Conversation with the Situation* (see Tables 9, 10, and 11) shows that the regression model is significant ($F(2, 470) = 24.5$, $p < .001$). *Self-efficacy* significantly affected this factor ($b = 0.294$, $p < .001$), suggesting that individuals with higher *self-efficacy* are likelier to value the attitudes associated with Factor 2. We also see *ambiguity tolerance* positively related to this factor ($b = 0.130$, $p = 0.024$) even though it is not as influential as *self-efficacy*.

Seeing *self-efficacy* highlighted by the results fits with our initial framing of Factor 2 as being related to *Conversation with the Situation*. Higher self-efficacy scores may reflect a greater willingness to share ideas with others as a measure of confidence in one's ability. Sharing ideas can put designers on the spot. People tend to put a lot of themselves into their ideas, and a rejection of an idea can feel like a rejection of oneself. It relies on a designer's confidence in their ability to effectively express and convey their creative thoughts and even having good ideas in the first place. Conversely, those with lower *self-efficacy* may be more hesitant to engage in such conversations, doubting their ability to contribute meaningfully or fearing potential criticism; this is especially relevant if ideas are outside the box and challenge others' perspectives and understanding of the design problem. A belief in one's abilities to overcome challenges and communicate ideas might thus be

Table 9. Model Summary – Factor 2: Conversation with the Situation

Model	R	R^2	Adjusted R^2	RMSE	R^2 Change	F Change	$df1$	$df2$	p
1			0.000	0.803	0.000		0	472	
2	0.291	0.084	0.083	0.769	0.084	43.456	1	471	< .001
3	0.307	0.094	0.091	0.766	0.010	5.153	1	470	0.024

Table 10. ANOVA – Conversation with the Situation

Model		Sum of squares	df	Mean square	F	p
2	Regression	25.7	1	25.7	43.5	< .001
	Residual	278.6	471	0.6		
	Total	304.3	472			
3	Regression	28.7	2	14.4	24.5	< .001
	Residual	275.6	470	0.6		
	Total	304.3	472			

Note. The intercept model is omitted, as no meaningful information can be shown.

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Table 11. Coefficients – Conversation with the Situation

Model		Unstandardized (b)	SE	Standardized (β)	t	p	95% CI Lower	95% CI Upper
1	(Intercept)	6.031	0.037		163.347	< .001	5.96	
2	(Intercept)	4.340	0.259		16.769	< .001	3.83	4.85
	Self-efficacy	0.326	0.049	0.291	6.592	< .001	0.23	0.42
3	(Intercept)	3.928	0.315		12.461	< .001	3.31	4.55
	Self-efficacy	0.294	0.051	0.262	5.732	< .001	0.19	0.40
	Ambiguity tolerance	0.130	0.057	0.104	2.270	0.024	0.02	0.24

Note. The following covariate was considered but not included: Sensation-seeking.

necessary to engage with the situation, indicating that those scoring high in *self-efficacy* are likelier to invest effort and persevere in the cumbersome processes of building shared understanding (see Bandura 1977, 1997).

Concerning *ambiguity tolerance*, it likely plays a similar role as in relation to Factor 1. *Conversation with the Situation* requires an acceptance of the inherent uncertainty and ambiguity that accompanies design processes. Individuals who are tolerant of ambiguity are more likely to be comfortable entertaining other perspectives and ideas (Herman *et al.* 2010; Mahmoud *et al.* 2020). *Conversation with the Situation* can be seen as a means to navigate and make sense of this ambiguity, as it invites diverse perspectives that can shed light on previously unnoticed aspects of the design space. Where *self-efficacy* likely acts as a catalyst for investing effort in conversations with the situation, *ambiguity tolerance* likely lets individuals thrive in exchanging insights and ideas.

This model accounted for 9.4% of the variance in scores in Factor 2 of *D-Mindset0.1* (see Table 9).

7.4. Factor 3: co-evolution of problem–solution

In the case of Factor 3, the regression analysis yielded a significant regression model ($F(2, 470) = 8.7$, $p < .001$; see Table 13), again showing a positive correlation with *ambiguity tolerance* ($b = 0.212$, $p = 0.004$) and *self-efficacy* ($b = 0.136$, $p = 0.039$; see Table 14). This model accounted for 3.6% of the variance in Factor 3 of *D-Mindset0.1-* scores (see Table 12).

Table 12. Model Summary – Factor 3: Co-Evolution of Problem–Solution

Model	R	R^2	Adjusted R^2	RMSE	R^2 change	F change	$df1$	$df2$	p
1			0.000	0.996	0.000		0	472	
2	0.164	0.027	0.025	0.983	0.027	13.001	1	471	< .001
3	0.189	0.036	0.032	0.980	0.009	4.304	1	470	0.039

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Table 13. ANOVA – Co-Evolution of Problem–Solution

Model		Sum of squares	*df*	Mean square	*F*	*p*
2	Regression	12.6	1	12.6	13.0	< .001
	Residual	455.5	471	1.0		
	Total	468.1	472			
3	Regression	16.7	2	8.4	8.7	< .001
	Residual	451.4	470	1.0		
	Total	468.1	472			

Note. The intercept model is omitted, as no meaningful information can be shown.

Table 14. Coefficients – Co-Evolution of Problem–Solution

Model		Unstandardized (b)	SE	Standardized (β)	t	p	95% CI Lower	95% CI Upper
1	(Intercept)	4.970	0.046		108.550	< .001	4.880	5.060
2	(Intercept)	3.835	0.318		12.053	< .001	3.210	4.460
	Ambiguity tolerance	0.255	0.071	0.164	3.606	< .001	0.116	0.393
3	(Intercept)	3.317	0.403		8.222	< .001	2.524	4.110
	Ambiguity tolerance	0.212	0.073	0.137	2.901	0.004	0.069	0.356
	Self-efficacy	0.136	0.066	0.098	2.075	0.039	0.007	0.265

Note. The following covariate was considered but not included: sensation-seeking.

As encapsulated in *D-Mindset0.1*, *Co-Evolution of Problem–Solution* is primarily about challenging the problem statement and spending time in the problem space. We related this more generally to framing and reframing problems (Dorst and Cross 2001; Dorst 2015) and suspending final decisions about the solution (Crismond and Adams 2012). As such, our initial framing of Factor 3 would have suggested *that ambiguity tolerance* should have been the more influential of the two included personality traits. Being comfortable with ambiguous situations likely translates into a positive attitude toward dwelling in the problem space despite feeling no closer to finding a solution to the problem. Again, self-efficacy seems to provide the necessary confidence, persistence and effort to do so. As such, this regression analysis sheds limited light on our interpretation of this subconstruct.

7.5. Factor 4: imagination

The analysis of Factor 4 also resulted in a significant regression model ($F(2, 470) = 18.4$, $p < .001$; see Table 16). Here, *sensation-seeking* is the only variable with a significant relationship ($b = 0.182$, $p < .001$; see Table 17). This relationship seems to align somewhat with our initial framing of Factor 4.

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Table 15. Model Summary – Factor 4: Imagination

Model	*R*	R^2	Adjusted R^2	RMSE	R^2 *Change*	*F* Change	*df1*	*df2*	*p*
1			0.000	1.133	0.000		0	472	
2	0.194	0.038	0.036	1.113	0.038	18.376	1	471	< .001

While the nature of the relationship is inconclusive (McDaniel *et al.* 2001), *sensation-seeking* has previously been related to *imagination*. Zuckerman (1994) concludes that sensation seekers are less prone to fantasies due to their tendency to active lives. However, Franken and Rowland's (1990) research indicates that sensation seekers have a rich and varied fantasy life. Similarly, McDaniel *et al.* (2001) conclude that daydreaming is a form of stimulation correlating with *sensation-seeking*. From this perspective, sensation seekers seem well-adapted to hypothetical thinking and likelier to engage in thought experiments and ideas outside the norm, aligning with Factor 4 of *D-Mindset0.1*.

Furthermore, *sensation-seeking* has previously been observed to correlate with divergent thinking (Zuckerman 1979; McCrae 1987), which fits our framing in relation to divergent thinking. However, based on the connection with divergent thinking, we would also have expected *ambiguity tolerance* to positively correlate with Factor 4.

This model explained 3.8% of the variance in Factor 4 of D-Mindset0.1-scores (see Table 15).

8. Evaluating the inventory

An essential step in developing an inventory is to evaluate it (Abell *et al.* 2009). This section delves into the assessment of the *D-Mindset0.1*, encompassing construct validity and reliability, to ensure that the inventory measures *design mindset* as intended and does so in a reliable way.

8.1. Construct validity

With the foundation in design theory, represented by Crismond and Adams' (2012) *Informed Design Teaching & Learning Matrix*, and the positive feedback on the items' theoretical relevance throughout the development process (see Section 4), we are confident that the items are relevant and capture design values and beliefs. The fact that the items of *D-Mindset0.1* load to factors in a theoretically

Table 16. ANOVA – Imagination

Model		Sum of squares	*df*	Mean square	*F*	*p*
2	Regression	22.8	1	22.8	18.4	< .001
	Residual	583.3	471	1.2		
	Total	606.0	472			

Note. The intercept model is omitted, as no meaningful information can be shown.

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Table 17. Coefficients – Imagination

Model		Unstandardized	SE	Standardized	t	p	95% CI Lower	95% CI Upper
1	(Intercept)	3.742	0.052		71.823	< .001	3.640	3.844
2	(Intercept)	2.950	0.192		15.393	< .001	2.574	3.327
	Sensation-seeking	0.182	0.042	0.194	4.287	< .001	0.099	0.266

Note. The following covariates were considered but not included: Ambiguity tolerance, Self-efficacy.

meaningful way further supports the validity of the inventory. In other words, the items included in *D-Mindset0.1* appear to capture core tenants of *design mindset.*

Supporting this, the Design and Innovation students with more design education had higher overall in *D-Mindset0.1-scores* than students from other programs with less design training. The average score across the 10 included items for Design and Innovation students (n = 15; M = 4.9) and the rest of the sample (n = 458; M = 4.4) was significantly different, $t(471) = -3.79$, Cohen's $d = 0.995$, $p < .001$, the groups meeting the assumption of homogeneity of variance as tested using Levene's test ($p > .05$). Cohen's d qualifies this difference as a large effect ($d > 0.8$), according to Cohen (2013). These results indicate that our inventory, at the very least, is sensitive to design-specific properties, as intended.

Lastly, the correlation between *D-Mindset0.1* in its entirety and *ambiguity tolerance* and *self-efficacy* found in the regression analysis lends further confidence in the inventory capturing design-relevant properties. That being said, the regression analyses of the subconstructs indicate that more research is needed to understand what they precisely capture.

8.2. Reliability

To ensure that the items in the inventory measure the same underlying construct reliably and consistently, we calculated McDonald's Omega for the entire inventory and each factor individually. McDonald's Omega indicates the extent to which the items are interrelated and measures the same.

For the entire *D-Mindset0.1*, McDonald's Omega (ω) is 0.52 [CI 95% 0.43..0.60]. Falling short of the generally accepted threshold for acceptable scales (>0.70) (Nunnally 1978), this indicates that the reliability of the inventory should be improved. However, Nunnally (1978) emphasized that the interpretation of reliability coefficients should consider both the nature of the measured construct and the instrument's intended purpose and application. Considering the complex and multifaceted nature of *design mindset* and that this study is in the early stage of development of the inventory, a lower reliability coefficient is acceptable (Nunnally 1978). In light of this, a McDonald's Omega of 0.52 is sufficient for this initial operationalization and exploration of *design mindset.*

Analyzing the factors separately (see Table 18), we see Factors 1 and 2 having a higher internal consistency than the overall inventory, indicating a stronger coherence within these subsets of items. The internal consistency of Factors 3 and 4 is more problematic, suggesting that further refinement is especially needed

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Table 18. McDonald's omega (ω)		
Factor		McDonald's omega (ω)
1	Iteration	0.65 [CI 95% 0.58..0.71]
2	Conversation with the Situation	0.65 [CI 95% 0.54..0.74]
3	Co-Evolution of Problem–Solution	0.23 [CI 95% 0.06..0.38]
4	Imagination	0.39 [CI 95% 0.26..0.50]

to enhance the reliability of these subconstructs. However, it is worth noting that "…reliability is a characteristic of the test scores, not of the test itself" (Streiner 2003, p. 101) and depends on the sample as well as the quality of the items. Further item analysis is required to determine whether the low consistency results from the sub-optimal design of the inventory or the complexity of the underlying phenomenon of *design mindset*.

9. Discussion

The aim of this article was to develop and validate an inventory for measuring *design mindset* by operationalizing existing theories on design strategies and behaviors and placing it in relation to core design theories and associated personality traits.

D-Mindset0.1 constitutes a significant step toward assessing *design mindset* and investigating its relationship to other aspects of design practices. Despite the relatively low reliability of the inventory (see section 8.2), it serves as a valuable tool for initial exploration and identification of key dimensions within the construct of *design mindset*. By defining and quantifying the construct, we have been able to identify four underlying structures of *design mindset*, providing us with a new perspective on existing theory.

The transition from Crismond and Adams' (2012) strategies to the four factors of *D-Mindset0.1* (see Figure 1), where none of the original item pairs loaded into the same factor, highlights the interconnectedness of design behaviors and mindset. It shows the importance of distinguishing between mindset and behaviors to understand their relationship. Analyzing the items of each factor revealed an alignment with design behaviors on a higher level of abstraction, connecting to high-level design theories as outlined in Section 6. As could be expected, values or beliefs, as represented by the items of *D-Mindset0.1*, do not only inform or align with single design strategies or behaviors but seem to cut across several.

In contrast to existing instruments for measuring *design mindset*, we narrowly focused on attitudes and beliefs related to design practice to directly evaluate mindset. In this way, the *D-Mindset0.1* has allowed us to investigate the relationship between *design mindset* and key personality traits in isolation. Rather than including design-related personality traits directly in *D-Mindset0.1*, we have shown that *self-efficacy*, *sensation-seeking* and *ambiguity tolerance* are not uniformly correlated with all factors of *design mindset* but rather relate to specific components.

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Unsurprisingly, *ambiguity tolerance* and *self-efficacy* emerge as significant in several of the regression models for the underlying factors of *D-Mindset0.1*. Even though the items of *D-Mindset0.1* are not explicitly about *ambiguity tolerance* or *self-efficacy*, both traits are crucial in the design process and are often ascribed to designers. We see *ambiguity tolerance* and *self-efficacy* together in the models for Factors 2 (*Conversation with the Situation*) and 3 (*Co-Evolution of Problem–Solution*), while *ambiguity tolerance* is also significantly related to Factor 1 (*Iteration*).

Based on the generally strong relationship between *ambiguity tolerance* and *design mindset*, it is perhaps more surprising that we do not see significant relationships across all factors of *D-Mindset0.1*. This is especially so when constructs have a shared connection to a concept, as in the case of *ambiguity tolerance* and *Imagination*, both connected to divergent thinking. Not finding a significant correlation between *ambiguity tolerance* and *Imagination* indicates the complex nature of the constructs and our limited understanding of them and their relationships. While *ambiguity tolerance* might intuitively be related to *Imagination* through their shared connection to divergent thinking, it is worth remembering that *D-Mindset0.1* measures values and beliefs, not actual performance or practice. *Imagination* is likely to capture something different than performance measures of divergent thinking and, consequently, not reflect the same relationship to *ambiguity tolerance*. This highlights that our understanding of *design mindset* would benefit from connecting *D-Mindset0.1* scores to performance both generally and on design tasks related directly to our framing of the subconstructs.

Unlike the other two personality traits, *sensation-seeking* was found to have no significant correlations with *D-Mindset0.1* in its entirety. We have indicated that this might be due to the less direct connection to design based on the shared relationship with risk-taking. As we also see in our interpretations of the relationships to the subconstructs, we mainly build these on the core tenets of *sensation-seeking* rather than its connection to risk-taking. *Sensation-seeking*'s multi-directional relationship with the subconstructs *Iteration* and *Imagination* highlights that different elements of *design mindset* are reinforced by different personality traits and values, indicating that individuals might struggle more with certain aspects of designing while others come more naturally. Understanding these dynamics has implications for how design educators and practitioners approach the development of *design mindset*. Ultimately, by examining the interconnectedness of *design mindset* and other traits, we can advance our comprehension of the multifaceted nature of design cognition and behavior, fostering more informed interventions and strategies within design education and practice, tailoring design methodologies to address individual shortcomings and optimize creative problem-solving within the design domain.

9.1. Limitations and future research

It is vital to acknowledge that no inventory can completely capture a complex construct like *design mindset*. As a result of our narrow framing of *design mindset* in direct relation to design practices, excluding more general components, we recognize that the *D-Mindset0.1* does not capture all aspects relevant to *design mindset*. For example, Crismond and Adams (2012) acknowledge that their matrix does not cover the role of social interactions in designing, and we further excluded the

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strategy *Troubleshoot* in constructing the inventory (see Section 4.2). The relatively low cumulative proportion of the total variance explained by the factors (see Section 5) also suggests that additional aspects of *design mindset* might yet be uncovered. Furthermore, the high *uniqueness* scores of some of the excluded items (see Table 1) indicate that they might capture something relevant to *design mindset* even though they did not load into any factors, suggesting a focus for further inventory development.

Similarly, our choice to only include two items for each of Crismond and Adams' (2012) strategies means we might have missed nuances of the core construct, adding to the risk of construct underrepresentation (see Abell *et al.* 2009), which reduces the precision of exploratory factor analysis and the quality of the identified factors (Watkins 2018). Besides, the low reliability indicates that the items of *D-Mindset0.1* might not consistently measure the underlying construct. Consequently, the results may include measurement errors and affect the precision of our findings. Future research should explore ways to improve the reliability of *D-Mindset0.1* to enhance its accuracy.

The low number of items in each factor also means that the theoretical underpinnings of the four factors of *D-Mindset0.1* are subject to relatively high uncertainty. Deriving the theoretical underpinnings of a factor based only on a few items runs the risk of drawing false conclusions. This is especially true in cases like Factor 4 (*Imagination*), where the existing design theory connecting attitudes toward future thinking and generating many ideas is limited. Generally, it is worth noting that: "Just because a factor is named does not mean that the hypothetical construct is understood or even correctly labeled" (Kline 2016, p. 300). Investigating the relationships between *design mindset* and *self-efficacy*, *sensation-seeking* and *ambiguity tolerance* is thus only the first step toward understanding what are, at this point, essentially statistical abstractions. Furthermore, our exploratory approach to the regression analyses of the subconstructs comes with the risk of confirmation bias, post hoc rationalization and overinterpreting the results. Consequently, the current labels and the theoretical underpinnings of the four factors should be seen as hypotheses that still need to be tested. They are, like the inventory itself, preliminary and require further research to establish the validity of our framing.

In other words, there is room for further exploration and expansion of the *D-Mindset0.1*. The statistical investigation of the subconstructs indicates that more research is needed before we can be sure what they exactly capture. The relatively low variance explained by each regression model indicates that we still have much to learn about the relationships between *design mindset* and what informs it. Researching the relationship between *design mindset* and variables, such as experiences, educational backgrounds or situational factors, is likely to enhance our understanding of *design mindset*.

Finally, *D-Mindset0.1* is anchored in engineering design, with its foundation in Crismond and Adams' (2012) matrix and the population it has been tested within. While the inventory seems to capture design-related properties related to design training within this population, as evidenced by the *t*-test, further research is needed to establish if it does so across design domains and disciplines. Other design domains might center around other design practices and thus not share the same values and beliefs. Furthermore, a central hypothesis is that *design mindset* correlates with performance; this is not necessarily true outside the domain of design engineering, where practice might not align with the ones highlighted by Crismond and

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Adams (2012). In any case, it is important to investigate the relationships between *design mindset* and performance on domain-specific design tasks to establish the generalizability and applicability of *D-Mindset0.1* across design domains.

Despite its shortcomings, the *D-Mindset0.1* takes a significant step toward operationalizing the construct of *design mindset*. In quantifying *the construct*, the inventory opens up for statistical analysis and testing of hypotheses necessary for driving theory building within design research.

10. Conclusion

This article has operationalized the construct of *design mindset* and developed *D-Mindset0.1*, allowing us to measure *design mindset*. The operationalization revealed four underlying factors of *design mindset* – *Iteration*, *Conversation with the Situation*, *Co-Evolution of Problem–Solution* and *Imagination* – pointing toward the fundamental values and beliefs supporting effective design practice. Investigating how these factors relate to the personality traits of *sensation-seeking*, *self-efficacy* and *ambiguity tolerance*, which previously have been connected to creativity and design behaviors, we see that the different factors of *D-Mindset0.1* align with different personality traits, providing a more nuanced understanding of *design mindset*, personality and behavioral characteristics. The article also shows how operationalizing constructs like *design mindset* can help further our understanding of core design concepts.

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Appendix A

DTU

0% completed

You are being invited to participate in a research study titled Innovation mindset. You were selected to participate in this study because of your participation in the course Innovation in engineering at DTU. This study is conducted by Jakob Clemen Lavrsen from the Technical University of Denmark – DTU.

This survey is part of the courses 'Innovation in Engineering' and 'Facilitating Innovation in Multidisciplinary teams. The purpose of this survey is twofold. First, it aims to trigger reflections regarding aspects of your personality in the context of innovation that will be the foundation for an exercise later. At the same time, it aims to research innovation mindset and its relation to other personality traits. You will be asked to complete two online questionnaires, one now and one at the end of the course. It will take you approximately 20 minutes to complete each..

We will collect data on personality traits, innovation mindset, and demographic data (e.g., age, gender). We will also ask you for your student identification number in order to connect the two datasets. After this, the data will be anonymized. The data will be stored on secured servers at DTU.

We hope that your participation in the study will expand our knowledge of innovation and how to develop innovation competencies. This research study is conducted by Jakob Clemen Lavrsen from the Technical University of Denmark – DTU. If you have questions about this project or a research-related problem, you may contact the researcher, Jakob Clemen Lavrsen (jclla@dtu.dk).

By clicking "I agree" below, you indicate that you are at least 18 years old, have read and understood this consent form, and agree to participate in this research study. Please print a copy of this page for your records. If you click "Next" without selecting "I agree", your data will not be used for research purposes.

○ Yes, I agree

Please type in the six digits of your DTU student identification number. Your student ID will only be used for connecting data from the two questionnaires.

Student ID

Next

Jakob Clemen Lavrsen, Technical University of Denmark - DTU – 2021

Leave and delete my data

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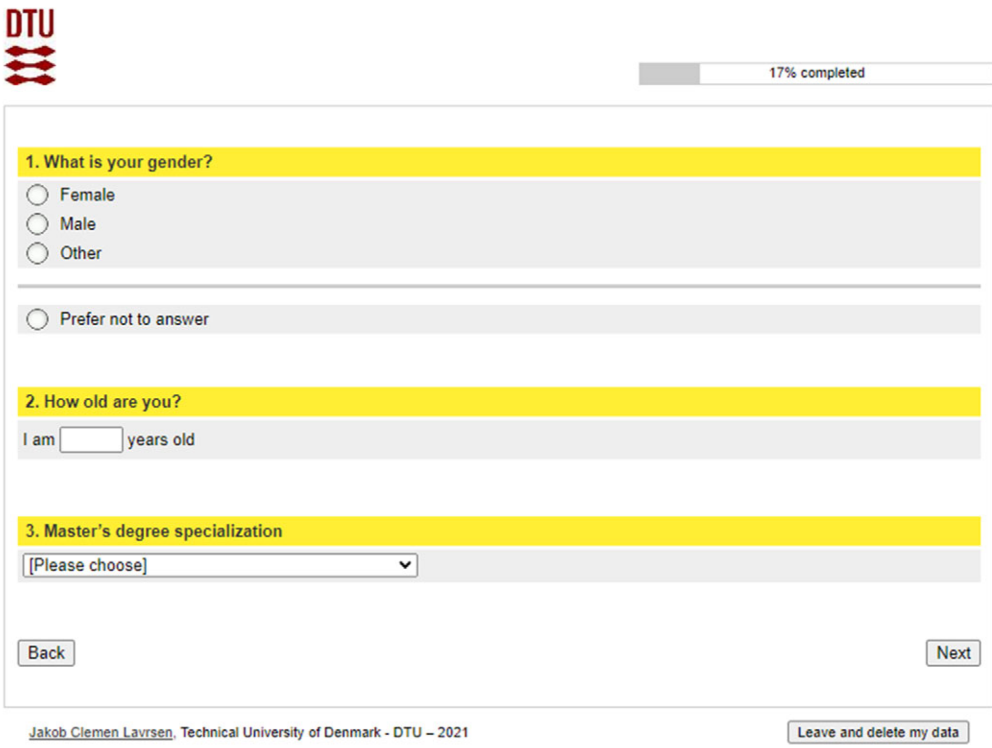


DTU

17% completed

1. What is your gender?

Female

Male

Other

Prefer not to answer

2. How old are you?

I am [ ] years old

3. Master's degree specialization

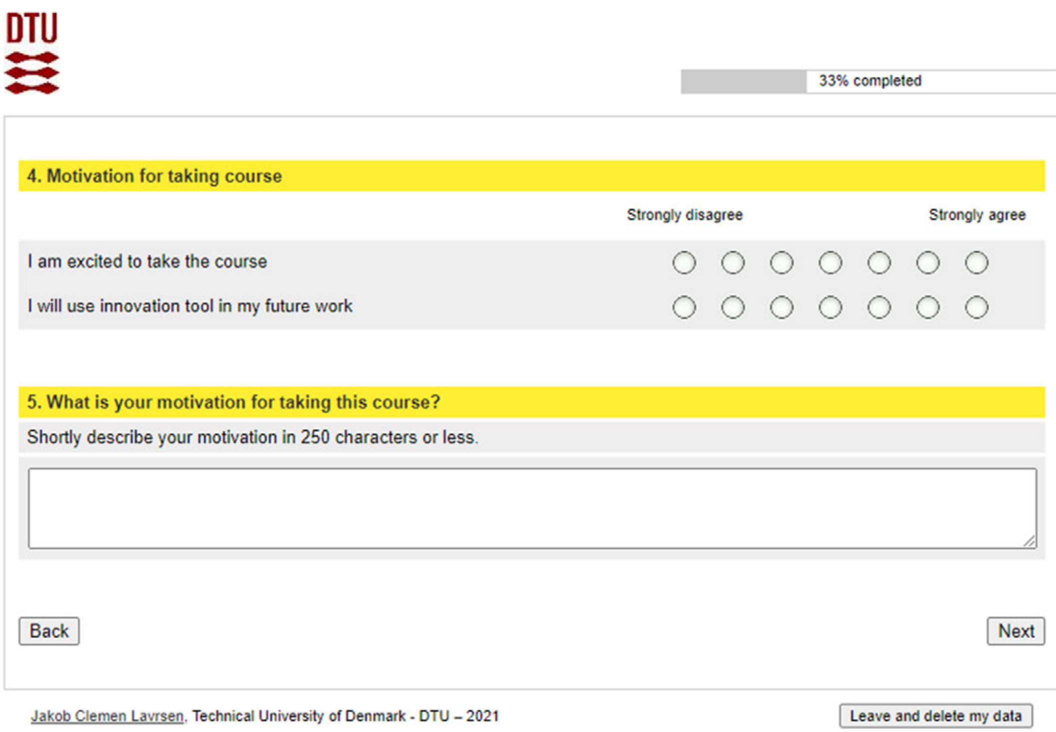
[Please choose]

Back

Next

Jakob Clemen Lavrsen, Technical University of Denmark - DTU – 2021

Leave and delete my data



DTU

33% completed

4. Motivation for taking course

	Strongly disagree						Strongly agree
I am excited to take the course	○	○	○	○	○	○	○
I will use innovation tool in my future work	○	○	○	○	○	○	○

5. What is your motivation for taking this course?

Shortly describe your motivation in 250 characters or less.

Back

Next

Jakob Clemen Lavrsen, Technical University of Denmark - DTU – 2021

Leave and delete my data

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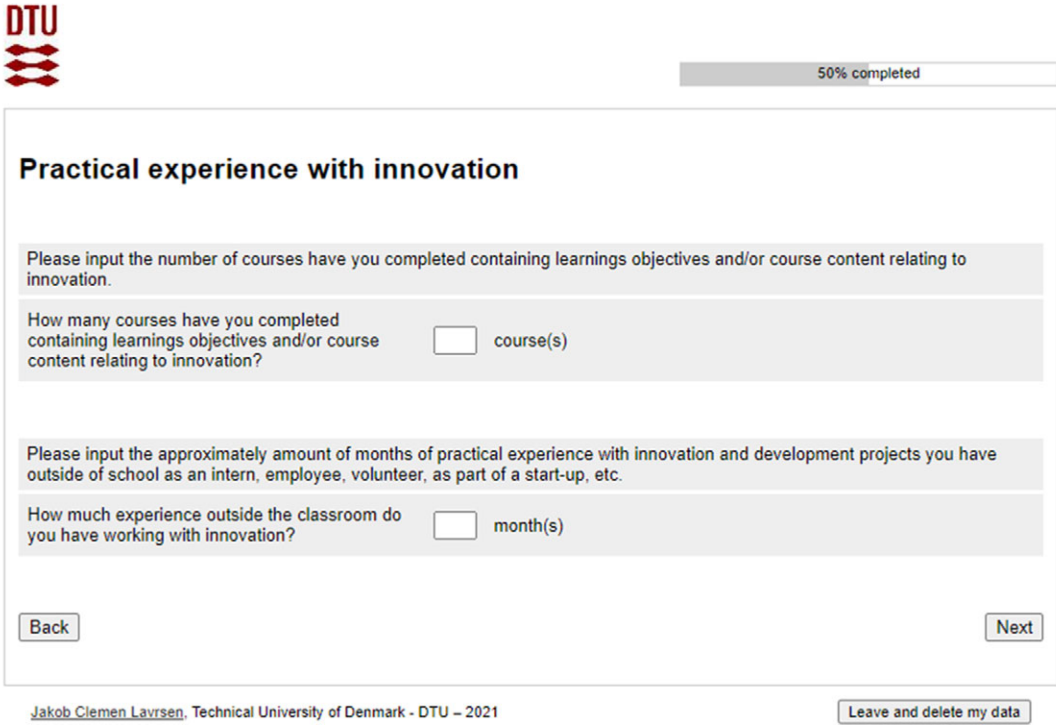

DTU

50% completed

Practical experience with innovation

Please input the number of courses have you completed containing learnings objectives and/or course content relating to innovation.

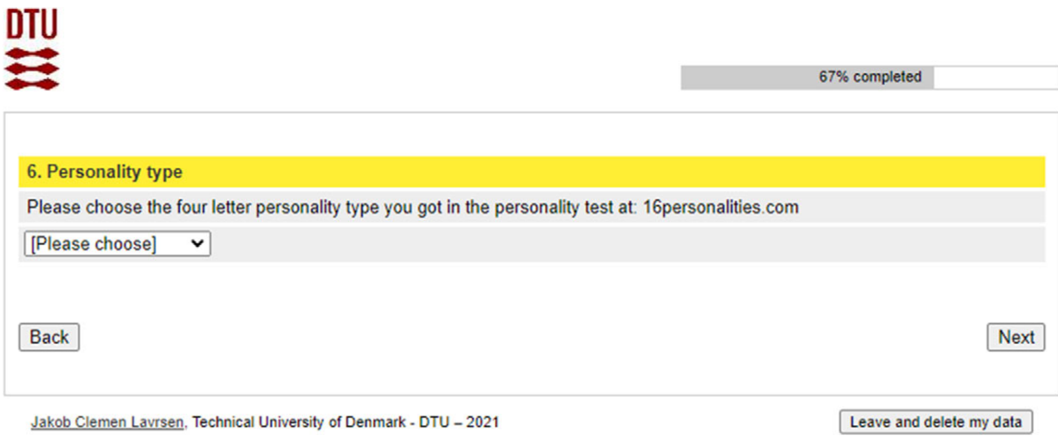
How many courses have you completed containing learnings objectives and/or course content relating to innovation? course(s)

Please input the approximately amount of months of practical experience with innovation and development projects you have outside of school as an intern, employee, volunteer, as part of a start-up, etc.

How much experience outside the classroom do you have working with innovation? month(s)

Back Next

Jakob Clemen Lavrsen, Technical University of Denmark - DTU – 2021 Leave and delete my data


DTU

67% completed

6. Personality type

Please choose the four letter personality type you got in the personality test at: 16personalities.com

[Please choose]

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83% completed

Personality traits and innovation mindset

Please indicate to what degree you agree or disagree with the following statements.

	Strongly disagree 0	1	2	3	4	5	Strongly agree 6
I avoid settings where people don't share my values.	○	○	○	○	○	○	○
I can enjoy being with people whose values are very different from mine.	○	○	○	○	○	○	○
I would like to live in a foreign country for a while.	○	○	○	○	○	○	○
I like to surround myself with things that are familiar to me.	○	○	○	○	○	○	○
The sooner we all acquire similar values and ideals the better.	○	○	○	○	○	○	○
I can be comfortable with nearly all kinds of people.	○	○	○	○	○	○	○
If given a choice, I will usually visit a foreign country rather than vacation at home.	○	○	○	○	○	○	○
A good teacher is one who makes you wonder about your way of looking at things.	○	○	○	○	○	○	○
A good job is one where what is to be done and how it is to be done are always clear.	○	○	○	○	○	○	○
A person who leads an even, regular life in which few surprises or unexpected happenings arise really has a lot to be grateful for.	○	○	○	○	○	○	○
What we are used to is always preferable to what is unfamiliar.	○	○	○	○	○	○	○
I like parties where I know most of the people more than ones where all or most of the people are complete strangers.	○	○	○	○	○	○	○

	Strongly disagree						Strongly agree
I can always manage to solve difficult problems if I try hard enough.	○	○	○	○	○	○	○
If someone opposes me, I can find the means and ways to get what I want.	○	○	○	○	○	○	○
It is easy for me to stick to my aims and accomplish my goals.	○	○	○	○	○	○	○
I am confident that I could deal efficiently with unexpected events.	○	○	○	○	○	○	○
Thanks to my resourcefulness, I know how to handle unforeseen situations.	○	○	○	○	○	○	○
I can solve most problems if I invest the necessary effort.	○	○	○	○	○	○	○
I can remain calm when facing difficulties because I can rely on my coping abilities.	○	○	○	○	○	○	○
When I am confronted with a problem, I can usually find several solutions.	○	○	○	○	○	○	○
If I am in trouble, I can usually think of a solution.	○	○	○	○	○	○	○
I can usually handle whatever comes my way	○	○	○	○	○	○	○

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	Strongly disagree						Strongly agree
I would like to explore strange places.	○	○	○	○	○	○	○
I get restless when I spend too much time at home.	○	○	○	○	○	○	○
I like to do frightening things.	○	○	○	○	○	○	○
I like wild parties.	○	○	○	○	○	○	○
I would like to take off on a trip with no pre-planned routes or timetables.	○	○	○	○	○	○	○
I prefer friends who are excitingly unpredictable.	○	○	○	○	○	○	○
I would like to try bungee jumping.	○	○	○	○	○	○	○
I would love to have new and exciting experiences, even if they are illegal.	○	○	○	○	○	○	○

	Strongly disagree						Strongly agree
It is important to challenge the problem statement before trying to solve the problemy.	○	○	○	○	○	○	○
Problems should be well defined and fully understood before attempting to develop a solution.	○	○	○	○	○	○	○
To make the future better, you should not try to solve today's problems but imagine a new future.	○	○	○	○	○	○	○
You should spend more time on building the solution then understand the question.	○	○	○	○	○	○	○
It is more important to spend time generating many ideas than it is to refine a few.	○	○	○	○	○	○	○
As soon as you have a good idea, you should move from idea generation to idea refinement.	○	○	○	○	○	○	○
Representing ideas in non-verbal ways – using diagrams, sketches, prototypes, dramatization, etc. – are essential in understanding a problem.	○	○	○	○	○	○	○
Sharing ideas with others throughout the process makes them better.	○	○	○	○	○	○	○
It is important to look at a solution from different stakeholder perspectives.	○	○	○	○	○	○	○
Once you have a good idea, you should not waste time figuring out how it might fail.	○	○	○	○	○	○	○
A failed experiment can be as important as a successful one.	○	○	○	○	○	○	○
It is more important to spend time testing continuously than to test the end-result.	○	○	○	○	○	○	○
Even late in the process, you should pivot and rethink a solution if learning something important.	○	○	○	○	○	○	○
If done right, you should not have to revisit past stages of the innovations process.	○	○	○	○	○	○	○
It is more important to follow a process than to adapt to the circumstances.	○	○	○	○	○	○	○
Methods are more a guideline than rules you must follow.	○	○	○	○	○	○	○

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DTU

Thank you for completing this questionnaire!

We would like to thank you very much for helping us.

Your answers were transmitted, you may close the browser window or tab now.

Jakob Clemen Lavrsen, Technical University of Denmark - DTU – 2021

Appendix B

Level	Counts	Total	Proportion (%)
Advanced Materials and Healthcare Engineering	2	473	0.4
Applied Chemistry	5	473	1.1
Architectural Engineering	46	473	9.7
Autonomous Systems	22	473	4.7
Bioinformatics and Systems Biology	9	473	1.9
Biomedical Engineering	2	473	0.4
Biotechnology	35	473	7.4
Business Analytics	16	473	3.4
Chemical and Biochemical Engineering	35	473	7.4
Civil Engineering	32	473	6.8
Computer Science and Engineering	25	473	5.3
Design and Innovation	15	473	3.2
Earth and Space Physics and Engineering	11	473	2.3
Electrical Engineering	24	473	5.1
Engineering Acoustics	5	473	1.1
Environmental Engineering	5	473	1.1
Food Technology	5	473	1.1
Human-Centered Artificial Intelligence	2	473	0.4
Industrial Engineering and Management	37	473	7.8
Materials and Manufacturing Engineering	10	473	2.1
Mathematical Modelling and Computation	2	473	0.4

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Level	Counts	Total	Proportion (%)
Mechanical Engineering	13	473	2.8
Pharmaceutical Design and Engineering	28	473	5.9
Photonics Engineering	1	473	0.2
Physics and Nanotechnology	2	473	0.4
Sustainable Energy	64	473	13.5
Technology Entrepreneurship (cand.tech.)	2	473	0.4
Transport and Logistics	9	473	1.9
Wind Energy	6	473	1.3
Other	3	473	0.6