METHOD OVER MADNESS

INVESTIGATING THE INTERACTION BETWEEN DESIGNERS, THEIR MINDSET AND DESIGN METHODS ON A COGNITIVE LEVEL

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Ph.D. Dissertation

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Summary (English)

This dissertation, *Methods over Madness: Investigating the Interaction between Designers, their Mindset, and Design Methods on a Cognitive Level*, contributes to the understanding of how designers engage with design methods by exploring the cognitive dynamics of their interaction. As design methods are increasingly called upon to address abstract, systemic challenges, the need to comprehend how these tools function in practice becomes critical. This work situates this investigation within the growing body of design research that frames methods not merely as prescriptive guidelines but as adaptive mental tools both shaping method usage and the method users.

The research addresses the overarching question: **How does the interaction between method and method user influence the user and the usage of methods in design?** It does so through two interconnected lines of inquiry: the role of the designer's mindset in method usage and the influence of cognitive load on design behaviours. These inquiries contribute to advancing the theoretical understanding of method usage while addressing gaps in existing research regarding how the interaction between methods and method users influences method usage.

The first inquiry focuses on *design mindset*. Article I defines and operationalises the construct, resulting in the development of the *Design Mindset Inventory (D-Mindset0.1)*, a psychometric instrument designed to measure it and four underlying constructs: *Conversation with the Situation, Iteration, Co-Evolution of Problem–Solution*, and *Imagination*. The inventory also establishes connections between these facets and relevant personality traits such as *ambiguity tolerance*, *self-efficacy*, and *sensation-seeking*, contributing to a nuanced understanding of the method user. Article II extends this investigation by examining how method teaching influences the development of *design mindset*. Using a quasi-experimental research design, it demonstrates that both individual traits and contextual factors significantly shape *design mindset* development, offering a framework for understanding how designers learn through method usage.

The second inquiry investigates *cognitive load* in relation to design and method usage. Cognitive Load Theory provides a lens through which the mental effort associated with method use can be understood in relation to complex and iterative design processes. Article III develops a conceptual framework linking *cognitive load* to design activities, with a particular emphasis on framing and reframing practices. Article IV complements this by empirically exploring *cognitive efficiency*—how designers balance performance and mental effort—through a pilot study comparing heuristic and systematic design methods in an idea-generation task. Together, these articles highlight the cognitive constraints designers find themselves under when navigating a problem space and using design methods.

The dissertation positions design methods as flexible, interpretive tools rather than rigid, procedural frameworks, foregrounding the critical role of the designer in contextualising and adapting methods to fit evolving challenges. By integrating perspectives on *design mindset* and *cognitive load*, the research contributes a theoretical foundation for understanding method usage and its implications for design practice and education. This work aligns with efforts in design research to formalise a theory of methods usage in design, validate methods effectiveness, and ultimately support the creation of methods that respond to both cognitive and practical needs.

By addressing these dimensions, this dissertation aspires to inform ongoing debates within design research while offering actionable insights for educators, practitioners, and method developers. It emphasises the interplay between cognitive processes and the reflective practice of design, ultimately contributing to the broader goal of advancing design methods as tools for innovation in an increasingly complex world.

Summary (Dansk)

Denne afhandling, *Methods over Madness: Investigating the Interaction between Designers, their Mindset, and Design Methods on a Cognitive Level*, bidrager til forståelsen af, hvordan designere arbejder med designmetoder ved at undersøge de kognitive dynamikker i deres interaktion. Da designmetoder i stigende grad anvendes til at adressere abstrakte og systemiske udfordringer, bliver det afgørende at forstå, hvordan disse værktøjer fungerer i praksis. Afhandlingen tager sit afsæt i det voksende perspektiv på designmetoder, hvor de ikke blot betragtes som regler der skal følges, men som mentale værktøjer, der både former metodebrug og påvirker metodebrugerne.

Afhandlingen udforsker det overordnede spørgsmål: **Hvordan påvirker interaktionen mellem metode og metodebruger både brugeren og brugen af metoder i design?** Spørgsmålet undersøges gennem to sammenhængende forskningsspor, centreret henholdsvis omkring *design mindset*, og *cognitive load* som en faktor der påvirker designadfærd. Disse undersøgelser bidrager til en teoretisk forståelse af metodebrug, samtidig med at de udfylder forskningsmæssige huller omkring, hvordan samspillet mellem metoder og deres brugere påvirker metodebrug.

Det første forskningsspor fokuserer på design mindset. Artikel I definerer og operationaliserer begrebet, hvilket fører til udviklingen af *Design Mindset Inventory* (*D-Mindset0.1*), et psykometrisk instrument designet til at måle *design mindset* og dets fire underliggende komponenter: *Conversation with the Situation, Iteration, Co-Evolution of Problem–Solution* og *Imagination*. Instrumentet afdækker også forbindelser mellem disse facetter og relevante personlighedstræk som *ambiguity tolerance*, *self-efficacy*, og *sensation-seeking*, hvilket bidrager til en mere nuanceret forståelse af metodebrugeren. Artikel II udvider denne undersøgelse ved at analysere, hvordan undervisning i metoder påvirker udviklingen af *design mindset*. Gennem et kvasi-eksperimentelt forskningsdesign påvises det, at både individuelle træk og kontekstuelle faktorer spiller en væsentlig rolle i udviklingen af *design mindset*, og der opstilles en model til at forstå, hvordan designere lærer gennem metodebrug.

Det andet forskningsspor undersøger *cognitive load* i relation til design og metodebrug. Cognitive Load Theory tilbyder et perspektiv på den mentale indsats, der kræves for at anvende metoder i komplekse og iterative designprocesser. Artikel III præsenterer en konceptuel model, der kobler *cognitive load* til designaktiviteter med særligt fokus på rammesætningen af design situationer. Artikel IV supplerer dette ved empirisk at undersøge *cognitive efficiency* – hvordan designere balancerer performance og kognitive indsats – gennem et pilotstudie, der sammenligner heuristiske og systematiske designmetoder i en idégenereringsopgave. Samlet fremhæver disse artikler de kognitive begrænsninger, som designere oplever, når de navigerer design problemer og anvender designmetoder.

Afhandlingen positionerer designmetoder som fleksible og reflekterende værktøjer frem for rigide og procedurebaserede rammer, og fremhæver derved designerens centrale rolle i at kontekstualisere og tilpasse metoder til skiftende udfordringer. Ved at integrere perspektiverne *design mindset* og *cognitive load* bidrager forskningen med et teoretisk grundlag for at forstå metodebrug og dens implikationer for designpraksis og -uddannelse. Dette arbejde taler ind i de voksende bestræbelser indenfor designforskningen på at opbygge teorier om metodebrug i design, valideringen af designmetoder, og understøttelsen af udviklingen af metoder som imødekommer metodebrugeres kognitive og praktiske behov.

Ved at adressere disse dimensioner sigter denne afhandling mod at informere de igangværende debatter inden for designforskning og tilbyde brugbare indsigter til undervisere, praktikere og metodeudviklere. Den understreger samspillet mellem kognitive processer og refleksiv designpraksis og bidrager således til det bredere mål om at fremme designmetoder som værktøjer til innovation i en stadigt mere kompleks verden.

‘Though this be madness, yet there is method in ’t’

(Shakespeare, 2012, *Hamlet*, Act 2, p. 95)

Preface

When I began my bachelor's degree in fashion design in 2009, I never imagined that I would one day find myself researching design methods; I just wanted to make creativity a career. Nevertheless, looking back, I already possessed a curiosity about the design process and a hunger for understanding its ins and outs. This curiosity has followed me through my educational and professional career, and when the opportunity arose to delve into it, I jumped on it and never looked back.

If not before starting my PhD, then fairly early on, I knew I wanted to title my dissertation: *Method over Madness*. While the creative process might look like madness for the uninitiated, there is system to it and more importantly, it is not irrational. This is also why I chose to preface this dissertation with Polonius' words from *Hamlet*: *"Though this be madness, yet there is method in 't"* (Shakespeare, 2012, p. 95).

Besides capturing the often chaotic, complex, and ambiguous nature of designing, the quote also captures the monumental task of doing a PhD. The first couple of months of my PhD were hectic, to say the least. I had barely arrived at the Technical University of Denmark (DTU) before my supervisor, Jaap Dalhuizen, suggested I write a conference paper for DRS22, with a deadline only one month away. Helped by an extended deadline and my co-authors, I got my first academic paper accepted and published. In parallel, we somehow managed to prepare my first study, and after just three months at DTU, we collected my first data, which, in combination with extensive reading and learning how to do statistical analysis, ended up being at the centre of most of my PhD project. Looking back, it would have been better practice to do it the other way around, but then again, the purpose of doing a PhD is to learn. This dissertation represents a little more than three years of exploration into the interaction between design methods and their users. While my understanding of design practices has evolved, I am still not satisfied that I have made significant strides towards understanding design practices or method usage. If anything, I have more unanswered (research) questions than when I started, but I am fairly certain that is the point.

I am deeply grateful to DTU for funding my project and to my supervisors, *Jaap Daalhuizen*, *John Paulin Hansen,* and *Claus-Christian Carbon*, for their guidance and encouragement. My colleagues, both at DTU and beyond, have enriched my research with diverse perspectives and invaluable feedback. Special thanks to my fellow design PhD candidates—*Andy Mattulat Filipovic*, *Camilla Kirstine Elisabeth Bay Brix Nielsen*, and *Carolina Falcão Duarte*—for countless discussions about design, as well as to Björgvin Hjartarson for sparring, climbing, hiking both local and international, introductions to awesome people, and generally good times. Lastly, to my friends and family, thank you for ensuring that work was not the only thing in my life. None of this would have been possible without you, or at least it would not have been the same.

... and I still cannot believe that somebody has been paying me for geeking out over design methods and design practices. It has been a privilege and a joy, and I would do it all over again in a heartbeat.

Odense, Denmark, November 2024

Jakob Clemen Lavrsen

Content

1 Introduction

Design is essential in shaping the world around us. Most of what surrounds us has in some way been designed, from the coffee machine that helps us get going in the morning to the car we drive, the road we drive on, the services that deliver groceries to our front doors or let us stream films directly to our screens, even much of what we call nature has been shaped by design.

Over the last decades, designers have been called on to take greater responsibility for the impact of the products and solutions they create (Davis, 2017; Findeli, 2001; Fry, 2009; Meyer & Norman, 2020; Oppenheimer, 2020). At the same time, design has increasingly been called upon to solve the most complex challenges facing both society and the environment (Brown, 2009; Fry, 2009), expanding the realm of design (R. Buchanan, 2001; Tromp & Hekkert, 2019) and putting design methods into the hands of people outside the traditional design fields (E. B.-N. Sanders & Stappers, 2008).

With the expanded scope of design and the potential for greater consequences resulting from applying design approaches to more critical challenges, the requirements to design methods and the need for quality methods have never been higher (Cash, Daalhuizen, et al., 2023). However, the theory surrounding method development has not kept pace with these demands. Even though the development of design methods is one of the main avenues through which design research impacts design practice (Blessing & Chakrabarti, 2009; Cantamessa, 2003; Daalhuizen & Cash, 2021), and the central role of design methods in design education and practice (Andreasen, 2003; Daalhuizen et al., 2014; Jones, 1992; Newstetter, 1998; Shreeve, 2015), little is known about how design methods work and what determines their performance. The interaction between design methods and method users is especially underexplored in design research (Dorst, 2008). Consequently, the current validation of design methods' effectiveness does not meet the standards of fields comparable to design (Cash, Daalhuizen, et al., 2023).

1.1 Design Method in Design Research

Design research as a research field evolved from, e.g., the operations and management, decision-making, and creativity research growing out of the innovations of World War II, with an aim to spur on creativity and innovation in the post-war era (Cross, 2007). These different strains of research influenced early examples of design methods and methodologies (see for example Alexander, 1964; Archer, 1965; Asimow, 1962; Jones, 1992 (1970); Osborn, 1963).

Through the 1960's the field was occupied with 'scientising' design, perhaps best represented by Herbert Simon's (1996 (1969)) *The Science of the Artificial* (Cross, 2007). The first generation of design methods aligned with positivism, focusing on formalising and rationalising design activities (Cross, 2008; Lloyd, 2019). This resulted in systematic and prescriptive approaches and methods, with top-down, algorithm-like, and hierarchical procedures (Bender & Blessing, 2004; Cross, 2008; Guindon, 1990). The overall aim of these methods was to formalise best practices, manage complexity, facilitate teamwork, and limit mistakes in the design process and failures of products (Cross, 2008; Daalhuizen, 2014).

Heralded by the likes of Hubka (1982) and Pahl et al. (2007), the systematic perspective on design methods still dominates, especially engineering design, to this day (Cross, 2007; Lloyd, 2019), resulting in a focus within design research into design methods predominantly on the process, to the exclusion of the design content, the designer, and the design context (Dorst, 2008).

However, since the '70s, the systematic perspective on design methods has been criticised for the rationalising of design methods (Lloyd, 2019) and for making designers 'act like machines' (Jones, 1980, p. 173) (Cross, 2007; Lloyd, 2019), a criticism echoed by later authors highlighting that the systematic methods seldom reflect how designers actually work (Bender & Blessing, 2004; Cross, 2008; Jensen & Andreasen, 2010).

The general assumption behind the systematic design methods seems to be that designers can and will follow design methods as prescribed—like a roadmap to predetermined outcomes (Daalhuizen, 2014; Daalhuizen et al., 2014). However, designers tend to deviate from prescribed approaches in response to the design context and emergent opportunities (Guindon, 1990). Furthermore, systematically following a design method is no guarantee for a successful design process (Curry, 2014; Daalhuizen et al., 2014; Daalhuizen & Cash, 2021). Method usage is affected directly by the 'staging' of the method, i.e., how it is chosen and used in relation to the specific design situation, context, and process (Daalhuizen & Cash, 2021; Mansoori et al., 2023), including any constraints imposed by available resources, organisational structures, or requirements. Likewise, the appropriateness and affordance of a method for the specific design situation and context need to be assessed (Badke-Schaub et al., 2011; Daalhuizen & Hjatarson, 2022; Gericke et al., 2016; Newstetter, 1998), which furthermore depends on the available information about the context, the information contained in the method, and the mindset through which the method user interprets the information (Daalhuizen & Cash, 2021). In this symbiotic relationship between the method, the context, and the method user, the method user emerges as the central actor, interpreting and translating the wider design context and facilitating any potential synergies between the components at play in the design situation. As such, method usage requires reflexivity (Bender & Blessing, 2004) and reflection-in-action (Adams et al., 2003; Schön, 1983) to respond to the evolving design situation throughout the process of using a method (Daalhuizen & Cash, 2021), suggesting that the method user must invest considerable cognitive effort and resources to effectively apply design methods. Reflecting these insights, design methods have, over the last decade, moved from the highly structured linear approaches to increasingly being framed as mental tools (Daalhuizen, 2014) or tools for encouraging '...more reflective, meaningful, and socially responsible design practices' (Gray, 2022, p. 1).

However, despite the recent efforts made to build theory around design methods (Daalhuizen & Cash, 2021; Gericke et al., 2020; Gray, 2022), and the validation of them (Cash, Daalhuizen, et al., 2023; Vermaas, 2016), research on the interaction between design methods and their users remains sparse (Daalhuizen, 2014; Daalhuizen & Cash, 2021; Dorst, 2008; Gericke et al., 2017). Considering the central role of the method user in method usage, the lack of research on the interaction between the method user and the design methods is bound to limit our understanding of the phenomenon and development of design methods. To ensure that design methods can handle the greater demands put on them by the expanded scope of use and to improve the method development and validation process of design methods, it is necessary to better understand the fundamental interaction between design methods and method users (Cash, Daalhuizen, et al., 2023). By investigating the interaction between method users and design methods, identifying core components, constructs, and their relationships, such research would contribute to the development of a coherent theory of method usage in design to the benefit of design research more generally (Cash, 2020; Daalhuizen & Cash, 2021). Such contributions would ultimately support the development of more effective, adaptable design methods that better align with the cognitive and practical needs of designers, advancing both design research and practice.

1.2 Research Questions and Aims

In response to the identified gap in design research, this dissertation aims to contribute to our understanding of the method user and their interaction with design methods. Consequently, this dissertation has been guided by the overall question:

How does the interaction between method and method user influence the user and the usage of methods in design?

To answer this question, this dissertation presents inquiries into two core constructs related to the method user and their interactions with design methods: *design mindset* and *cognitive load*. Following a theory-building approach, both inquiries focus on defining and describing the constructs, resulting in conceptual frameworks for empirical investigating of the relationship between method usage and the method user.

Inquiry I consist of Article I (Chapter 4) and Article II (Chapter 5). It investigates the construct of *design mindset* and its development. The designer's mindset is considered a central component of effective method usage, influencing how a method is understood, staged, and used (Andreasen, 2003; Daalhuizen & Cash, 2021; Mansoori et al., 2023). However, despite its importance, it is unclear what constitutes a designer's mindset and what factors influence its development. To address this, Article I defines and operationalises the construct *design mindset*. In doing so, Article I also connects *design mindset* to the three personality traits: *ambiguity tolerance, self-efficacy,* and *sensation-seeking*, which all have been connected to design or creativity (Bandura, 1997; Dosi et al., 2018; Mahmoud et al., 2020; Zuckerman, 1979) and, thus, help expand our general understanding of the method user.

Article II (Chapter 5) utilises the *Design Mindset Inventory (D-Mindset0.1),* developed in Article I, to investigate how individual and contextual factors influence the development of a *design mindset* through *method teaching/*method usage. In answering this question, Article II presents a framework of how method usage informs the development of *design mindset*, outlining core aspects of the interactions between design method and method user.

Together, the two articles of Inquiry I provide important insights into the relationship between design methods and method users in terms of their *design mindset* and personality traits.

Inquiry II consists of Article III (Chapter 6) and Article IV (Chapter 7). It investigates the construct of *cognitive load* and how it influences design behaviours and method usage. Cognitive load is the mental effort required to process information, solve problems, and make decisions (Sweller, 1988; Sweller et al., 2019). As a construct influenced by individual experience, expertise, and knowledge, as well as the nature of the problem, the condition of the situation and context, the process, and the availability and presentation of information (Hancock et al., 2021; Paas & Van Merriënboer, 1994; Sweller et al., 2019), *cognitive load* is informed by many of the same variables that are at play in method usage and, therefore, presents a promising operationalisation of the method user in relation to method usage.

Article III investigates the potential of cognitive load for understanding design behaviours and activities. In doing so, it outlines a conceptual framework for understanding design activities, especially the process of framing and reframing, through the lens of *cognitive load*.

Article IV (Chapter 7) continues this investigation of *cognitive load* by presenting a pilot study investigating how *Cognitive Efficiency* on an idea-generation task is influenced by using different types of design methods. *Cognitive Efficiency* is the ability to achieve goals with minimal cognitive effort (Paas & Van Merriënboer, 1993). Tying cognitive load and performance together, *Cognitive Efficiency* provides important insights into the mechanisms influencing design performance. Investigating this relationship, the study presented in Article IV also investigates four different measures of performance: three self-assessed measures related to the perceived novelty, usefulness, and satisfaction with the solution, and one rater-assessed measure related to how well the design task has been solved. As a multifaceted measure of efficiency, including both the experience of the method user and their performance, the investigation of *Cognitive Efficiency* helps us move towards a potential answer to how method performance can be evaluated.

An overview of the four included articles is provided in Table 1-1. Two additional conference articles have been published during the PhD project. While not substantially contributing to the main inquiries covered in this dissertation, and therefore not included in full, elements of *Towards a lifecycle of design methods* (Lavrsen et al., 2022) are used in Chapter 2 for context and referenced in other of the included articles. The award-winning[1] article *The Design Mindset Inventory (D-Mindset0): A Preliminary Instrument For Measuring Design Mindset* (Lavrsen et al., 2023) has been expanded, and its content is now generally covered by Article I of this dissertation.

In identifying and operationalising key constructs related to the method user and outlining conceptual models describing their relationship to method usage, the two inquiries provide important tools and insights for continuing the development of a theory of method usage in design. These contributions have the potential to further research into method usage and the development and evaluation of design methods. Adding to the understanding of method usage and the interaction between designers and their methods, the dissertation provides important insight into how design methods work and, thus, potentially into core design activities and practices. Moreover, highlighting the cognitive processes related to method usage also has the potential to inform metacognitive processes related to how designers think about designing and, thus, improve both design education and practice.

[1] Winner of both a Reviewers' Favorites Award and Design Science Journal's Excellence in Design Science Award at ICED2023.

TABLE 1-1: OVERVIEW OF THE INCLUDED ARTICLES IN THE DISSERTATION

	Inquiry I		**Inquiry II**	
	Article I	Article II	Article III	Article IV
Title	Measuring Design Mindset: Developing the Design Mindset Inventory through its relationship with ambiguity tolerance, self-efficacy, and sensation-seeking	Developing Design Mindset: How individual and contextual factors influence the development of Design Mindset through Method Teaching	Balancing Cognitive Load in Design Work: A Conceptual and Narrative Review	Cognitive Efficiency Using Heuristic vs Systematic Design Methods: Assessing Theoretical Foundations and Measures of Design Performance through a Pilot Study
Co-authors	Carbon, C. C. Daalhuizen, J.	Carbon, C. C. Daalhuizen, J.	Daalhuizen, J.	Carbon, C. C. Daalhuizen, J.
Status	In press	Published	Published	Submitted
Publisher	Design Science	Journal of Engineering Design	Design Research Society (DRS), Proceedings DRS2024	(Journal of Design Research)
Research questions	What is *design mindset*, and how do we measure it?	How do individual and contextual factors influence the development of *design mindset* through *method teaching*?	How can design practices be understood through the lens of *cognitive load*, and what implications does this perspective have for investigating these practices?	How do systematic versus heuristic design methods influence *cognitive efficiency* on an idea generation task?
Method(s)	Scale development, Statistical analyses (factor analysis, regression analyses)	Quasi-experimental pre-post-intervention research design, Statistical analyses (regression analyses)	Theory-building, Conceptual modelling, Narrative review	Independent, single-anonymized, single-factor, three-level experiment, Statistical analysis (ANCOVA)
Key contributions	Article I operationalise the construct of *design mindset* and develops the *Design Mindset Inventory* (*D-Mindset0.1*) to measure it. The inventory is revealed to measure four subconstructs: Conversation with the Situation, Iteration, Co-Evolution of Problem–Solution and Imagination, and being positively correlated with *ambiguity tolerance* and *Self-efficacy*.	Article II investigates student's development of *design mindset* through method usage and provides a conceptual framework for understanding the process through which this happens. The results show that method usage has a statistically significant and positive influence on *design mindset* but also that the learning process is influenced significantly by *ambiguity tolerance*, *Self-efficacy* and Sensation-seeking.	Article III presents a conceptual framework for understanding design activities through the lens of *cognitive load*, suggesting that *cognitive load* in the design process can be managed through efficient design activities. It does so by drawing upon theories rooted in cognitive science and information processing.	Article IV investigates *cognitive efficiency* related to using systematic versus heuristic design methods. The pilot study reveals that neither method significantly improved cognitive efficiency and highlights the challenges of capturing *cognitive load* and its impact on design performance, adding to the theoretical understanding of *cognitive efficiency* in design.

2 Theoretical Background

This chapter presents the theoretical foundation and background of this dissertation. It draws on the theory presented in each of the included articles to give a conceptual basis and overall understanding of the key phenomenon, concepts, and constructs under investigation. As such, it serves to tie the articles together and frame the further discussion of them in Chapter 8.

Firstly, the general concept of designing is outlined in *2.1 Design Activities*. This section provides an overall framing of design activities spanning the spectrum from design processes to the underlying cognitive processes supporting the achievement of design goals. Building on this, section 2.2 *Design Methods* defines and describes design methods, both in terms of their role in the design process and the manifestation of design methods as objects designers can interact with. Section *2.3 Interaction with Methods* outlines the different interactions between method users and methods throughout the lifecycle of design methods, highlighting the selection, adaption, and usage of design methods. Lastly, *2.4 Method User* introduces three aspects of the method user—personality traits, mindset, and cognitive capacity—which informs the framing of the method user in the four included articles.

2.1 Design Activities

Designing is a fundamental human activity (Heskett, 2002; Lawson & Dorst, 2009). Or as Herbert Simon formulates it: ‘Everyone designs who devises courses of action aimed at changing existing situations into preferred ones’ (Simon, 1996, p. 111).

Generally, design activities are the goal-directed cognitive and behavioural activities required to bring-into-being an artefact or intervention to achieve a design goal (Cash & Kreye, 2017, 2018). As these underlying cognitive processes and behavioural actions accumulate (Bedny & Harris, 2005; Cash & Kreye, 2017), they grow into design processes and potentially individual practices, codified design methods, processes and methodologies.

Design processes are a goal-directed sequence of activities (Gericke et al., 2020). The term can either describe a prescribed and formalised process or the specific sequence of activities as it emerges in a specific design situation (Gericke et al., 2020). Due to the varying goals of different design disciplines, some types of design activities are more dominant in some disciplines than in others. However, there are often common and shared traits across domains (Lawson & Dorst, 2009). We see this reflected in the commonalities between many formalised design and innovation processes across domains (see VanPatter & Pastor, 2016). For example, Stanford University D.school’s Design Thinking Process (Figure 2-1; Both & Baggereor, 2010) and the Double Diamond (Figure 2-2; Design Council, 2003) both highlight starting with some sort of exploration, followed by defining or framing the design space and then the generation and development of a solution. The D.school’s Design Thinking Process highlights prototyping and testing in the last stages, while The Double Diamond indicates a broader focus on implementation.

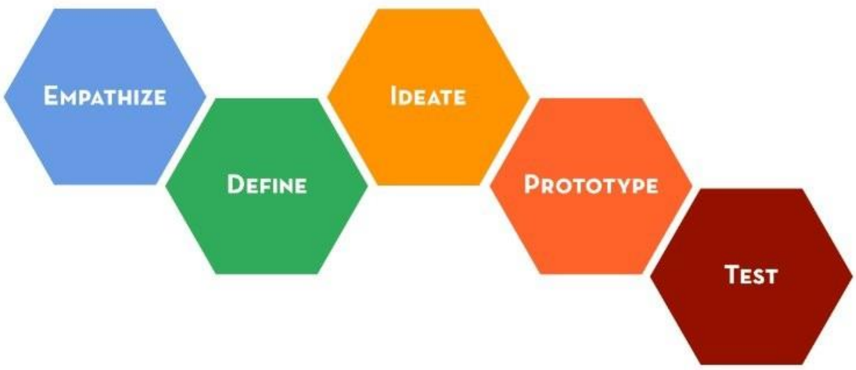

Figure 2-1: IDEO’s Design Thinking Process

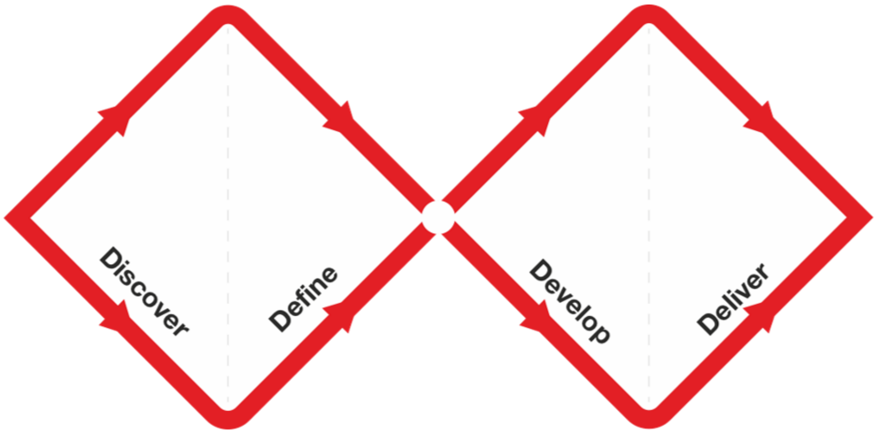

FIGURE 2-2: THE DOUBLE DIAMOND

Both visualisations suggest some level of linearity in the design process, downplaying the iterative nature of designing for a simpler model. However, design processes are seldom linear. As the design process progresses, it is often necessary to revisit earlier decisions and repeat activities related to earlier stages (Dorst, 2011). This dynamic nature of design activities has led some researchers to categorise design activities on a more fundamental level. Lawson and Dorst (2009), for example, suggest that design activities fall into the categories of *Formulate, Represent, Move, Evaluate*, and *Manage*. *Formulate* covers such activities as identifying and framing the design problem and the continuous definition of the design space. *Represent* covers the externalisation of output from the other activities in words, text, form or other forms of visualisation. *Move* covers the activities related to the continuous manipulation and rearranging of representations, framings and other information in the design space, which, in essence, are the core activities in generating solutions. *Evaluate*-activities regulate *Moves* and solutions by evaluating and making judgments between alternatives. *Manage* refers to the activities that relate to keeping the design process on track and include reflecting-in- and on-actions and making decisions on which specific activities to apply in response to the evolving design process.

Similarly, Cash and Kreye (2017) identify three core types of design actions: *information action*, *knowledge sharing action*, and *representation action*. Rooted in the underlying cognitive processes, they split the activities slightly differently than Lawson and Dorst (2009). For example, *Representation action* concerns the cognitive processes related to both internal and external representations and, therefore, includes aspects from across all of Lawson and Dorst's (2009) categories. *Information actions* are associated with the collection and handling of data and its transformation into knowledge. This relates strongest to Lawson and Dorst's (2009) *Evaluate* activities, but also include aspects categorised under, especially *Move*. Where *information actions* are about processing external sources of information, *knowledge sharing actions* are about formulating and sharing one's individual understanding to generate a shared understanding of the design context; it is about effective communication and facilitating group learning and creativity. These actions are mainly covered in Lawson and Dorst's (2009) *Formulate* and *Move* categories.

Compared to the activities on the process level, at the level of actions and cognitive processes, the flexibility and variation of design activities become clear. Characteristic for the more fundamental design activities is that they permeate all higher-level activities. They reflect the constant moving back and forth between thinking modes in response to the often non-linear process of designing; iterating, revisiting, and revising both the structure of information, the framing of the design space, and the understanding of the potential solution. As such, design methods, processes, and practices alike are sequences of these fundamental activities in response to the ever-evolving design situation. We see this reflected when, for example, Yilmaz et al. (2010) point to methods like TRIZ, SCAMPER, and Synetics as sources of heuristics, indicating that design methods can be deconstructed into simpler sequences of design activities.

Breaking down design activities into their underlying cognitive processes, as Cash and Kreye (2017) do, it becomes clear that designing is a multifaceted cognitive process (Cross, 2001; Finke et al., 1992; Hay et al., 2017). Furthermore, it also reveals that the cognitive process of designers is not fundamentally different from the cognitive processes of non-trained designers (Weisberg, 2009). Managing, structuring, and communicating information is fundamental to most human thinking, supporting that design is a fundamental human activity.

2.2 Design Methods

The term *design methods* is used in multiple ways within the design literature, covering a wide array of tools, frameworks, and approaches that vary significantly in both structure and purpose (Gericke et al., 2020, 2022). For some, design methods encompass anything that facilitates the design process (Cross, 2008; Jones, 1992). Others define design methods more narrowly as structured, prescriptive guidelines or instructions on how to achieve a particular result (Gericke et al., 2017). There are also different perspectives on the purpose of design methods. Some see them primarily as a means to optimise product development, focusing on improving efficiency and effectiveness in achieving high-quality solutions (Blessing & Chakrabarti, 2009; Jagtap et al., 2014), while others, such as Daalhuizen (2014), view them as 'mental tools' intended to shift mindsets and behaviours, promoting new ways of approaching and understanding design challenges.

Following the definition of design activities above, design methods are formalised sequences of activities aimed at advancing the design process toward a design goal. For a sequence of design activities to emerge in a designer's practice and be codified into a design method, the sequence must necessarily occur routinely (Daalhuizen, 2014; Lawson & Dorst, 2009). Furthermore, the situation of use must be predictable enough to ensure some level of success when the sequence of activities is applied and common enough to be relevant and warrant formalisation (Daalhuizen, 2014).

The formalisation of design activities makes them explicit—at least to a certain level. By formalising a sequence of design activities, they help designers break down the design process into more manageable components and design activities (Cross, 2008; Curry, 2014; Gericke et al., 2020). Design methods streamline the design process, provide scaffolding and structure, mitigate risk, oversights, and errors, and can ensure alignment with industry and safety standards and some control of performance (Cross, 2008; Curry, 2014; Hjartarson & Daalhuizen, 2021; Jagtap et al., 2014; Lawson & Dorst, 2009; Newstetter, 1998).

Through externalisation of design activities and thinking, design methods also make procedural and practical design knowledge accessible, teachable, shareable, and open to improvement (Cross, 2008; Dorst, 2008; Gericke et al., 2016; Jensen & Andreasen, 2010; Jones, 1992; Wallace, 2011). As carriers of procedural knowledge, design methods can, to some extent, stand in for practical experience (see Sweller, 2023) and help designers navigate unfamiliar or especially complex design situations (Schønheyder & Nordby, 2018). Additionally, design methods give teams a shared point of reference, helping them to coordinate, structure, and perform design tasks (Daalhuizen et al., 2019; Gericke et al., 2020; Jagtap et al., 2014). Consequently, design methods have been crucial in professionalising design practices (Jones, 1992). They scaffold learning, facilitating the development of design skills and practices (Curry, 2014; Daalhuizen et al., 2014; Jones, 1992; Newstetter, 1998; Shreeve, 2015), informing belief formation and design cognition (Cash, Daalhuizen, et al., 2023).

2.2.1 Design Methods as Mental Tools

While design methods provide benefits by structuring complex design processes and enabling more systematic approaches, they themselves do not ensure successful design processes or outcomes (Badke-Schaub & Frankenberger, 1999; Curry, 2014; Daalhuizen et al., 2014; Daalhuizen & Cash, 2021). As already covered, the method user is the central actor in method usage, interpreting, and translating the design method and context to determine the actions needed to achieve the design goals. As such, it becomes the ability of a method to prompt appropriate actions and design activities in relation to a design situation that determines the success of a method and, ultimately, the success of the design process.

Consequently, the definition of design methods as formalised sequences of activities is insufficient to capture the means by which methods generate value. Rather than procedures to be strictly followed, it is more fitting to frame them as mental tools (Daalhuizen, 2014). In this context, methods become resources that provide information about design activities in relation to design situations and components of the design context, supporting the designer in making sense of and navigating the design space (Daalhuizen, 2014). Therefore, design methods are better defined as the '... formalised representation of a design activity that functions as a mental tool to support designer to (learn how to) achieve a certain goal, in relation to certain circumstances and resources available' (Daalhuizen et al., 2019, p. 37).

This extended definition of design methods acknowledges the cognitive, adaptive, and situated nature of method usage, extending it beyond the execution of predefined procedures and into the realm of reflective and flexible problem-solving.

2.2.2 The Manifestation of Design Methods

While mental tools, as externalisations of design activities, design methods themselves are generally captured in some form of information artefact (Daalhuizen & Cash, 2021). Information artefacts are the human-made representation of information in physical or digital form (Marchionini, 2010). These information artefacts typically contain abstract models describing the structure of generic design situations and the design activities needed to manage them and produce specific outputs or outcomes (Daalhuizen, 2014).

Gray (2022) identifies three types of knowledge contained in design methods: *Codification-oriented, Performative*, and *Presentation-oriented*. The *Codification-oriented* knowledge relates to the formalised procedural and descriptive knowledge contained in the method. It includes *sensitising concepts*, *attributes*, and the *core*, which together provide the conceptual framing of the design methods and the design situation, placing it in relation to existing theories, concepts, practices, or outcomes (Gray, 2022), which generally aligns with the systematic approach to design.

While procedural and descriptive knowledge help position a method in relation to theory and practice and suggest a way forward, it might not be sufficient for applying a method in practice. Gray (2022) indicates that design methods should also contain *performative* knowledge. Performative knowledge involves the aspects of a method that are activated during its use by a designer, including the inputs, mechanics, and outputs that drive design action in a specific situation (Gray, 2022). It relates to the application of the formalised procedural and descriptive knowledge contained in the methods, and guidance of applying and adapting it to the specific content. As such, this knowledge is not disconnected from the formalised procedural and descriptive information but rather builds on it to ensure the practical implementation of a method. Therefore, the performative perspective on design methods aligns with the framing of methods as mental tools where the content of the method has to be interpreted in relation to the design situation and the users understanding of it. The performative information might be more or less explicit, depending on how abstract the method is presented. Ideally, a method should contain the necessary information for the effective adaption and application of a method to the context of use (Daalhuizen & Cash, 2021; Jagtap et al., 2014). However, methods often lack information on the tacit knowledge required for effective usage (Andreasen, 2003; Jänsch et al., 2005). As we move into method usage and the interaction between design methods and their users, we dig deeper into the role of performative knowledge in relation to method usage.

Cutting across these types of information, Daalhuizen and Cash (2021) specify the 'good' design methods should contain information about: *Method Goal, Method Procedure, Method Framing*, *Method Rationale,* and *Method Mindset*. *Method Goal* corresponds to the explicit purpose of the design method and should provide clear information about the design goals it will aid in achieving. *Method Procedure* refers to the sequence and logical structure of the design activities proposed to achieve the *Method Goal*. *Method Framing* sets the context for the use of the method, providing information about the situations in which the method is appropriate, the prerequisite factors for applying the method, and how it should be staged in relation to the context of use. *Method Rationale* justifies the method and the relationship between its components, providing information about the underlying motivation and relevance of achieving the *Method Goal*. Together, *Method Framing* and *Method Rationale* help position the method within the design situation, allowing the user to infer appropriate actions in the face of incomplete or conflicting information and observations. *Method Mindset* outlines the knowledge, beliefs, perspective on design, and values required by the user to implement the method effectively. Daalhuizen and Cash (2021) propose that method content resembles 'theory' in the sense that it organises knowledge about relevant variables, their relationships, and the domain of action (see Wacker, 2008), e.g., the actions needed to be taken to achieve the expected results. Like theory, the internal logic of a method should be consistent (Daalhuizen & Cash, 2021; Wacker, 1998). Consequently, the quality and internal logic of the information contained in a method influence the quality of the method (Daalhuizen & Cash, 2021).

Lastly, as information artefacts, design methods package and present this information. Gray (2022) highlights this in the presentation-oriented stance on design methods, which relates to the actual manifestation of the method in terms of the format, medium, and structures of guidance. Guidance structures refer to, e.g. steps, lenses, questions, heuristics, methodologies, frameworks, and guidelines, tying together the prescriptive *core* and performative *mechanics* of methods (Gray, 2022). The *medium* refers to the type of interface the designer interacts with, e.g., templates, card decks, worksheets, videos, tools, and games (Gray, 2022). The type of *medium* can be a presentation layer malleable to change, transforming the types of interactions facilitated by the method without changing the core elements of the procedural and descriptive information (Gray, 2022).

In combination, the manifestation of the method can determine what interactions and design activities it affords (Gray, 2022; T. Green & Blackwell, 1998). A specific manifestation might highlight some features of the design situation, ignoring others, increasing the affordance of some design activities over others (Daalhuizen, 2014; Dalsgaard, 2017). Doing so, the method helps the method user to prioritise features and structure design activities in response to the situation (Daalhuizen, 2014). In other words, the way methods are packaged and presented and the content they contain can have a huge impact on how the method is perceived, understood, and used (Daalhuizen & Cash, 2021; Gray, 2022; T. Green & Blackwell, 1998).

2.3 Interaction with Methods

Throughout the lifecycle of design methods, the nature of the interactions with a design method changes. The *Lifecycle of Design Methods* presented by Lavrsen et al. (2022)[2] outlines how designers interact with methods across different stages of development, dissemination, discovery, operationalisation, use, and internalisation (Figure 2-3).

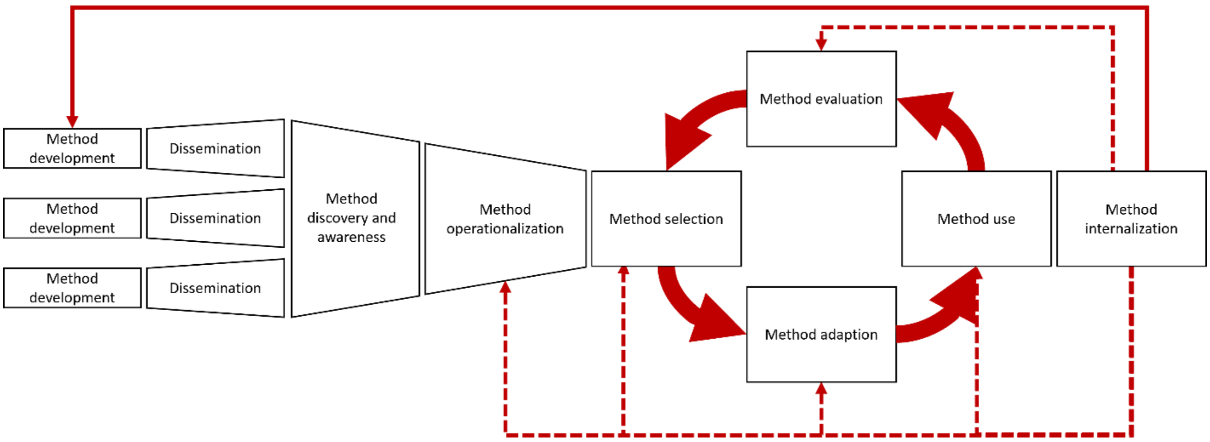

Figure 2-3: An updated model of the lifecycle of design methods as presented at DRS22

During *development*, the designer of the methods engages in the formalisation of design knowledge, either through a practice-driven, bottom-up approach or a theory-driven, top-down approach, shaping the manifestation of the method. During *dissemination*, interactions are characterised by efforts to introduce methods to practitioners, involving formal education and marketing strategies aimed at ensuring accessibility and buy-in. Moving from the method developer to the potential method user, in *method discovery and awareness,* the interaction is generally cursory as the potential user searches for methods to solve a challenge or improve their practice. *Operationalisation* refers to the process of becoming familiar with a method, assessing its relevance, and making any general adjustments to fit it to a domain and practice.

The central part of the *Lifecycle of Design Methods* is the method usage, here including the selection, adaption, use, and evaluation of the methods. In the use stage, interactions become more dynamic as designers select and adapt methods to fit their specific needs, requiring them to interpret and customise the methods in response to, e.g., their practice, the design problem, context, and stakeholders. Through method usage, methods might eventually be internalised, moving the designer away from explicitly following formal

[2] This article, while part of my research efforts and presented at a DRS2022, is not included in full within this dissertation. Although it provides an interesting exploration of the lifecycle of a design method, its contributions to my research are primarily to highlight the differences in interactions with a design method throughout its lifecycle. As such, it does not substantially advance the core research questions addressed in this dissertation and is therefore referenced here for context rather than included as a full chapter.

guidelines to integrating the core principles of these methods more fluidly into their practice. As such, as methods have been internalised, they cannot, strictly speaking, be considered methods anymore (Daalhuizen, 2014). They become co-opted by the designer's idiosyncrasies and embodied practices to form new practices that potentially can be formalised as new design methods, prompting a new cycle of the method lifecycle.

Method usage and *internalisation* make up the staging ground for the two strains of inquiry covered by the articles included in this dissertation. As indicated by the dashed-lined arrows of Figure 2-3, the two stages are interconnected, reflecting the intertwined relationship between the method usage and the method user.

2.3.1 Method Selection and Adaptation

Method usage is situational (Badke-Schaub & Frankenberger, 1999; Daalhuizen, 2014; Schön, 1983), and influenced by a complex network of factors such as the individual, the method, the design context, the social organisation, the specific design situation, and other external conditions (Badke-Schaub & Frankenberger, 1999; Daalhuizen, 2014; Gray, 2022).

Method usage covers the selection, adaption, use, and evaluation of a method (Figure 2-3). Unless the method is being prescribed by someone else, the selection of it is dependent on the designer's awareness of it and the assessment of its appropriateness and affordance in the specific situation (Badke-Schaub et al., 2011; Daalhuizen & Hjartarson, 2022; Gericke et al., 2016; Newstetter, 1998). In assessing a method, the potential method user must rely on the information provided by the method, their experience with the method or similar methods, their understanding of the design context, and the specific needs of the design situation based on their experience.

Adapting a method is a matter of recontextualising it to the specific design situation (Daalhuizen, 2014; Lavrsen et al., 2022). It could be to adjust the method *input* and *output* to fit the needs of the design process or change the *medium* to better fit the needs and organisation of the design team, e.g., transforming the method into a worksheet. It could also be necessary to make changes to the core content of the method, e.g., changing the procedure or framing of the method.

The extent to which method adaptation is necessary depends on the fit between the method and the situation of use. In a stable environment, very specific and precise methods might emerge that can be used again and again without considerable adaption or recontextualisation. However, design situations are rarely that stable. Method usage can be influenced by practically an infinite number of interrelated factors, warranting different actions and affording different opportunities (Daalhuizen, 2014). Furthermore, methods are often presented in an abstract or general form to allow them to be applied in a broader range of situations, which puts more responsibility on the method user in applying them appropriately. Like with method selection, the need to adapt and the adaptations made to a method depends on the method user's assessment of appropriateness based on their understanding of the method and the specific design situation. Disregarding the nature and needs of the specific situation of use, the method usage might not achieve the intended goals. However, changing the method too much and the method risks losing what ensured its efficacy and effectiveness (Lavrsen et al., 2022). As such, adaptation of methods becomes a balancing act between preserving the integrity of the method and making it appropriate in the design situation.

Daalhuizen and Cash (2021) suggest that quality *method content* helps facilitate the successful adaptation of methods by providing the necessary information to make informed decisions on the changes needed to be made. Discrepancies between the information available in the method and the information needed to successfully apply it can, for example, hinder appropriate application (Daalhuizen & Cash, 2021; Jänsch et al., 2005). In such cases, where important information has not been made explicit by the method, the method user must fill in the gaps by relying on their own knowledge and experience, highlighting the importance of their ability to interpret the information in relation to the design situation.

The adaptation of a method might not be as explicit, premeditated, systematic, or independent from method usage as suggested above (see Figure 2-3). The changes will often be a dynamic response to applying the method in practice, influenced by how the task is perceived, the interpretation of the context in which the method is being applied, the user's understanding of the method, and the requisite background knowledge, as well as factors such as motivation, personality, and other individual traits (Andreasen, 2003). Like in the design process itself, it is only through the implementation of a method that it becomes clear what factors of the design situation are salient for the successful implementation (Cross, 2008; Daalhuizen, 2014). If a method is appropriate or has been appropriately adapted, it should help provide a clear understanding of the design situation, frame thinking, and point a way forward, prompting appropriate actions (Daalhuizen, 2014).

2.3.2 Method Usage

As touched upon above, design methods are used to gain a lot of different benefits. Among other things, designers use methods to provide structure to an otherwise ambiguous process, handle unfamiliar or challenging design situations, coordinate design activities in a team, and develop new competencies (Cross, 2008; Curry, 2014; Hjartarson & Daalhuizen, 2021; Jones, 1980; Lawson & Dorst, 2009; Wallace, 2011). Designers may utilise methods throughout the design process to facilitate design activities like problem exploration and framing, ideation, prototyping, evaluating, communicating, or managing the design process.

As mental tools, using a method is a matter of cognitively processing and transforming the information contained in the methods into an actional understanding of the design situation and the activities needed to achieve the design goal (Daalhuizen, 2014). This places method usage as a reflective practice, as presented by Schön (1983), characterised as ‘a conversation with the materials of a situation’ (p. 78). The role of reflections in knowledge development and making sense of the world is laid out in Kolb's (2015) learning cycle presented in Chapter 5 in relation to learning through method usage and the development of *design mindset*. In short, reflection in and on action leads to a conceptualisation of the situation, informing new actions to test this framing, potentially improving the situation or the control over it, and prompting new actions, reflections, and learning (D. A. Kolb, 2015; Schön, 1983). In this process, the information contained in a method interacts with the user's practical experience, preferences, mental models, understanding of the design situation, and idiosyncrasies of practice to inform the designer's actions (Andreasen, 2003; Daalhuizen, 2014; Jensen & Andreasen, 2010). Daalhuizen and Cash (2021) have illustrated this interaction between the method and the method user, as shown in Figure 2-4.

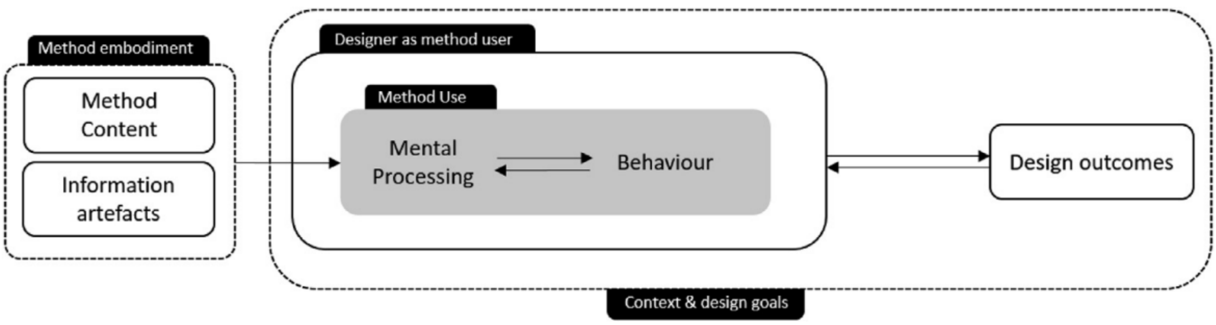

FIGURE 2-4: METHOD USAGE AS A MENTAL PROCESS IN RELATION TO THE METHOD, THE METHOD USER AND THE CONTEXT (DAALHUIZEN & CASH, 2021)

Being a reflective practice also places method usage in contrast to intuitive thinking. Stanovich (2009) places reflective thinking within System 2, the slower, more deliberate, resource-heavy, rational thinking system of the dual processing system of human thinking. In contrast, intuition is the driver of the faster, less cognitive taxing, and automatic responses of System 1 (Evans et al., 2005; Stanovich, 2009). System 1 is the default system, with System 2 monitoring and stepping in to overwrite if the intuitive response is deemed insufficient or if the (potential) outcomes do not align with expectations.

In addition to distinguishing between Systems 1 and 2, within System 2, Stanovich (2009) also distinguishes between the algorithmic and the reflective mind. The algorithmic mind handles cognitive tasks requiring fluid intelligence, such as working memory and computational processing. It focuses on decoupling representations and managing serial operations but operates within predefined rules and tasks (Daalhuizen, 2014; Stanovich, 2009). Conversely, the reflective mind is responsible for setting goals and regulating high-level epistemic thinking (Daalhuizen, 2014; Stanovich, 2009). It involves critical thinking dispositions, influencing decision-making beyond immediate task performance. This division between the algorithmic and reflective minds highlights a central difference in the cognitive processing related to method usage as a systematic versus a reflective practice (Daalhuizen, 2014). Methods usage as systematic aligns with the algorithmic mind, emphasising rule-following, efficiency, and defined processes (Stanovich, 2009). The algorithmic mind processes information in short- and long-term memory to match information and knowledge to make rational decisions. It is related to optimal performance, following specific norms (Daalhuizen, 2014). Meanwhile, the reflective mind is crucial in goal-setting, linking beliefs and actions, and prioritising. This reflective process involves not just following instructions but actively thinking through how the method aligns with their design goals and the context in which they are working. Thus, method usage as a reflective practice corresponds to the reflective mind, encouraging designers to think critically, reframe problems, and adjust their approach based on broader goals and contexts (Daalhuizen, 2014).

Despite the alignment with the two perspectives on method usage, in actual method usage, the two aspects of System 2 interact to allow effective use of design methods. The algorithmic mind provides the structure allowing for the effective alignment with the method procedure, while the reflective mind ensures the critical assessment of the appropriateness of methods, prompting adaption to align with the goals and the design situation. This interaction enables method users to follow the procedures of the methods while also ensuring that the method usage is adjusted as the design situation evolves.

Furthermore, the System 2 processing also interacts with the intuitive responses of System 1. System 2 processing is resource intensive, which is why the brain tends to default to System 1 processing when possible (Stanovich, 2009). Consequently, while appropriate method usage requires System 2 processing to actually follow a method (Daalhuizen, 2014), the assumptions made about the surrounding context and the decisions made to accommodate them to the design situation and method usage might very well be rooted in System 1 processing without any conscious considerations. The degree to which this is the case might be a matter of the nature of information related to these activities contained in the method. If, as proposed by Daalhuizen and Cash (2021), methods contain explicit information about how to stage the method usage and the rationale behind it, it might highlight aspects that need to be addressed, prompting System 2 thinking. Operating in System 2 requires a sustained overwriting of the intuitive responses to avoid defaulting to learned behaviours. In practice, this means that the designer might switch between the two systems of information processing, defaulting to the intuitive responses (inspired by the method), only reverting back to System 2 processing if something unexpected happens.

Method usage, framed as a reflective practice, naturally means that the benefits of using the method should continuously be evaluated. This might lead to further adaption or the abandonment of the method. Daalhuizen (2014) suggest that the use of a method should be abandoned as soon as it no longer serves the purpose of the designer. This might be to explore new opportunities (Bender & Blessing, 2004; Guindon, 1990), or because the method usage is no longer necessary to scaffold the design activities (see Chapter 5; Curry, 2014; Daalhuizen et al., 2014; Hjartarson & Daalhuizen, 2021; Lawson & Dorst, 2009; Newstetter, 1998; Royalty, 2018).

As methods become internalised through repeated use, they move from the explicit and reflective domain of System 2 into the intuitive and automatic realm of System 1 (Chandler, 1993; Daalhuizen & Hjartarson, 2022; Lavrsen et al., 2022; Paas & Van Merriënboer, 1994; Sweller et al., 2019). At this point, the method ceases to function as a formal tool and instead becomes part of the designer's embodied practice (see Daalhuizen, 2014), facilitating faster decision-making with minimal conscious effort. This transition illustrates the dynamic interplay between reflective, deliberate thinking and intuitive, experience-based responses in method usage. Ultimately, the appropriateness and performance of a method are determined by the fit between the method and the needs of the method user in the specific design situation (Badke-Schaub et al., 2011; Daalhuizen & Hjartarson, 2022; Gericke et al., 2016; Mansoori et al., 2023; Newstetter, 1998).

2.4 Method User

As made obvious above, the method user occupies a vital role in the phenomenon of method usage in design by transforming the method content into actions fitting for the design situation. However, the relationship between the method user and design methods is dynamic, and the interaction influences both the method usage and the method users themselves (Andreasen, 2003; Daalhuizen et al., 2014; Daalhuizen & Hjartarson, 2022; Royalty, 2018). Individual characteristics, like the method user's personality traits, experience, mindset, and cognitive capabilities, influence the interaction between design methods and the method user.

2.4.1 Personality Traits

The method user's individual personality traits play a significant role in how they engage with methods. Traits such as *Self-efficacy*, *Ambiguity tolerance*, and *Sensation-seeking* influence a designer's ability to confidently select and adapt methods to fit the design context. For instance, a designer with high *self-efficacy* may approach new methods with greater assurance, ready to experiment and modify them (see Bandura, 1997; Jobst et al., 2012; Kelley & Kelley, 2013), while someone with a high *ambiguity tolerance* will more easily navigate uncertain or open-ended design situations (see Budner, 1962; Herman et al., 2010; Mahmoud et al., 2020). Meanwhile, *Sensation-seeking* individuals might be more open to trying new methods and challenging social conventions in the design context (see Franken, 2002; Hoyle et al., 2002; Zuckerman, 1979, 1994; Zuckerman & Aluja, 2015). Articles I (Chapter 4) and II (Chapter 5) investigate the relationship between the three personality traits and *design mindset*.

2.4.2 Design Expertise and Mindset

Besides the more general personality traits, design-related practice knowledge and experience is another significant factor in method usage. Experienced designers are often better equipped to assess a method's relevance and adjust it to fit their unique design contexts (see Cross, 2008; Daalhuizen & Cash, 2021; Jänsch et al., 2005; Lawson & Dorst, 2009; Wallace, 2011). While novice designers might cling to the method, following it religiously, to bring them successfully through the design process, more experienced designers use methods more intuitively, customising them according to the demands of the situation (Cross, 2008; Jänsch et al., 2005; Lawson & Dorst, 2009; Wallace, 2011). The experience to do so is built up over time. Method usage encourages particular ways of thinking about and approaching design situations, which in turn influences the method user's overall approach to design problems. For example, method users exposed to iterative methods might acquire a preference for trial-and-error approaches. Through reflective practices, designers can develop a set of attitudes, beliefs, and approaches, internalising the underlying mechanisms, theory, and internal logic of a method into a so-called mindset (Andreasen, 2003; Daalhuizen, 2014; Daalhuizen et al., 2014).

Mindset is both a precondition for and a result of method usage, evolving as the designer gains experience and becomes more adept at navigating complex design processes. It influences how the method is staged (Mansoori et al., 2023), how it is used (Andreasen, 2003; Daalhuizen & Cash, 2021), and how the use is experienced (Daalhuizen et al., 2014). Therefore, a fit between the designers' mindset and a method is considered necessary for the successful application of the method (Andreasen, 2003; Daalhuizen & Cash, 2021).

The article presented in Chapter 4 (Article I) defines and operationalises *design mindset*. Building on this, Article II (Chapter 5) investigating the development of *design mindset* through method usage and the influence of the personality traits in doing so.

2.4.3 Cognitive Effort and Efficiency

As a cognitive activity, method usage in design involves information processing, decision-making, problem-solving, and reflection in response to the evolving design situations (Cross, 2001; Dorst, 2011; Finke et al., 1992; Hay et al., 2017). As outlined in Section 2.3.2, method usage can require a significant amount of cognitive processing and mental effort. However, human cognitive resources are not infinite. Our ability to process information is limited by the ability of working memory to maintain focus on relevant information and relate it to information in long-term memory (Hambrick & Engle, 2003; Miller, 1956; M. S. Sanders & McCormick, 1993; Stanovich, 2009). This means that the method user's level of training, expertise, and their resulting knowledge structures, directly influences how they engage with a design situation. While experienced designers can draw on established mental schemas and efficient strategies to manage cognitive demands and navigate the design situation, design methods should aid them when their training falls short or the situation is unfamiliar or particularly complex. Therefore, it is crucial to understand the impact of method usage on the user's *cognitive load* and their *cognitive efficiency*. *Cognitive load* refers to the strain put on cognitive resources when processing information and solving problems (Sweller, 1988; Sweller et al., 2019), while *cognitive efficiency* covers the efficiency by which these resources have been utilised to achieve a goal (Paas & Van Merriënboer, 1993). As a construct, *cognitive load* captures the effect of a wide range of variables, such as task complexity and experience (see Hancock et al., 2021; Paas & Van Merriënboer, 1994; Sweller et al., 2019), providing crucial information about how the method user experiences the design situation.

In articles III (Chapter 6) and IV (Chapter 7) design activities and method usage are investigated through the lens of *cognitive load*, thus highlighting additional components of the phenomenon of method usage and our understanding of the interaction between the method user and the method. In framing the method user in terms of *cognitive load*, we draw on research on human factors (e.g., Hancock et al., 2021; Xie & Salvendy, 2000) and Cognitive Load Theory (e.g., Paas & Van Merriënboer, 1993; Sweller et al., 2019).

2.5 Research Framework

This chapter has provided the foundation for understanding design methods, method usage, and the role of the method user within the design process. It begins by defining design methods as formalised sequences of activities that serve as mental tools, supporting designers in navigating and interpreting complex design situations to achieve specific goals. Drawing from design theory, the chapter emphasises that design methods encapsulate procedural knowledge, guiding designers in structuring and managing design activities, and are further shaped by their manifestation in information artefacts, which impact their interpretation and use.

The discussion of method usage highlights it as an interactive and reflective practice wherein designers adapt methods to suit evolving design contexts. Here, the method user is central, bridging the method's content with contextual demands and interpreting it through the lens of personal traits, knowledge, and experience. This adaptability of method usage aligns with the view of design as a fundamentally cognitive process, requiring flexibility, reflection, and iterative problem-solving, often under varying degrees of *cognitive load*.

Following this theoretical framework, this dissertation frames the method user in terms of *design mindset* and *cognitive load* to investigate the interaction between method users and methods. In doing so, the aim is to illuminate the central node of Daalhuizen and Cash's (2021) model of the interaction between the method and the method user (see Figure 2-4) to better understand the method users' role in method usage.

3 Research Methodology

In this chapter, the research approach adopted to address the overarching research question of this dissertation and the specific methodologies employed in each study to answer the corresponding research sub-questions are outlined. The chapter begins with an overview of the underlying philosophical assumptions guiding this work, followed by a positioning of the dissertation and each included article within the framework of theory-building and theory-testing paradigms. Lastly, the methodological choices for each study are presented, detailing the data collection and methods of analysis. Finally, I discuss how these methodological choices complement each other to support the dissertation's aim of advancing theoretical insights into the phenomenon of method usage in design.

3.1 Philosophy of Science

While most of the articles included in this dissertation take a quantitative approach, this does not reflect an overall positivistic theory of science. Rather, it reflects a pragmatist approach, recognising the relevance and importance of quantitative approaches in design research and theory development.

At its core, pragmatism holds that the world can only be known through action, not passive observation. In this perspective, knowledge is developed through the process of inquiry, where uncertainty and inconsistencies are resolved through deliberate investigation (Dewey, 1938). Inquiry is the general foundation for coming to know or understand something and consists of a cycle of problem identification, hypothesis generation, experimentation, and reflection (Dewey, 1938; Dixon, 2020). As such, they span the continuum from common knowledge to scientific research, with the difference primarily lying in the focus of the inquiry and the formality of the method of inquiry (Dixon, 2020). Inquiry is ongoing and self-corrective, with each step feeding back into the next, enabling researchers to refine their theories based on their utility and outcomes. The aim is to reach 'warranted assertions'—understandings of the world that let us navigate within it or can inform further inquiry (Dewey, 1938; Dixon, 2020). As such, for pragmatists, 'truth' is derived from the benefits it provides for a community's practices (Brinkmann, 2018), making theories provisional, and their validity determined by how well they serve the engagement with the world at any given moment. This contrasts with more positivist views, where theories are often seen as aiming to describe objective truths.

From the pragmatist perspective, the way we engage with the world and structure information can be seen as instruments of inquiry (Dalsgaard, 2017; Dewey, 1910), also meaning that the research methods used and the conceptual frameworks developed throughout this dissertation can be seen as instruments of inquiry. They function as boundary objects through which the world can be explored and understood. They frame the research, emphasising some facets not necessarily apparent otherwise and obscuring others, thus changing the perception and understanding of the phenomenon under investigation and the context of research, potentially transforming it and how we interact with it (see Dalsgaard, 2017). This approach to research underscores the importance of methodological pluralism, where the selection of methods is driven by the research question rather than an adherence to a single epistemological stance.

In line with the pragmatist concept of *knowing-through-action*, there is an aspect of exploratory research throughout the dissertation. Knowing-through-action is the construction and generation of new knowledge through action (Dalsgaard, 2017). It reflects that truth, according to pragmatism, is not something passively observed or discovered but something actively constructed through experience. It aligns with the idea of experienced-based learning, covered in more detail in Chapter 5, where learning happens as reflections on experiences are conceptualised and evaluated through experiments applying the new knowledge in practice (D. A. Kolb, 2015). As studies are designed, conducted, and analysed, new insight into the research methods and theoretical frameworks is gained, informing the process, decisions, and interpretation of the results. In this view, research is continuous and context-bound, leading to flexible, evolving theories that adapt as circumstances change. By building on the existing research to form conceptual frameworks and then test hypotheses based on these, this dissertation aims to offer a more comprehensive understanding of the phenomena of method usage, bridging the gap between theories and contributing to a more nuanced and robust body of knowledge in the field of design.

3.2 Theory-Building

Currently, research into design methods is fragmented. There is little explanatory theory and even less predictive theories of methods and their performance (Daalhuizen & Cash, 2021). Much of the descriptive insights generated are not being translated into formal models and frameworks nor tested or refined (Cash, 2020). To remedy this breakdown in the theory-building process, this dissertation takes a theory-building approach. Theory-building represents a build-up of scientific knowledge through cycles of exploration, theory development, systematisation, empirical scrutiny, and refinement (Cash, 2018). Its core aim is to explain the how, when (or where), and why of a phenomenon, identifying, defining, and describing the domain, the key variables, and their conceptual relationships to make predictions (Cash, 2018; Wacker, 1998, 2008).

Cash (2018) outlines the theory-building process as consisting of the following stages:

- Discovery and description
- Definition of variables and limitation of domain
- Relationship building
- Prediction, testing, and validation
- Extension and refinement

Due to the underexplored nature of the phenomenon of method usage in design, this dissertation primarily operates in the first stages of theory-building. It focuses on the description of the phenomenon, the definition of variables, and the establishment of relationships, with a few ventures into prediction, testing, and validation. Both inquiries of this dissertation shift between the exploration of existing knowledge relevant to method usage in design, operationalisation, and conceptual modelling and the initial empirical scrutiny, thus resampling theory-building (see Cash, 2018; Wacker, 1998).

While limited empirical discovery is presented, a significant portion of this dissertation is spent describing the phenomenon of method usage and its core components. To do so, it utilises existing research and literature both from within design and relevant fields like cognitive science and psychology. As such, much of the work done in the *Discovery and description* stage generally falls within what Wacker (1998) refer to as *analytical conceptual research*.

The conceptual work of describing the phenomenon facilitates the identification and definition of the core components of the phenomenon. In line with the underlying pragmatist approach, this process is generally exploratory, with definitions and models functioning as boundary objects for supporting the inquiries.

Inquiry I (Chapters 4 and 5) and Article IV (Chapter 7) of Inquiry II all aims to establish relationships: Article I, between *design mindset* and the personality traits *ambiguity tolerance*, *self-efficacy*, and *sensation-seeking*; Article II, Between method usage and the development of *design mindset*, and between this development and the personality traits; Article IV, Between the type of design method, *cognitive load*, and design performance. Article II and Article IV take this further by also testing hypotheses based on the predicted relationship between variables, e.g., showing that method usage positively influences *design mindset*. The discussion continues the relationship building, utilising the included research to propose relationships between *design mindset*, *cognitive load* and design performance, as well as predictions to be tested in future research. Together, the work presented in this dissertation contributes to the description, definition, identification, and preliminary testing of core components of the phenomenon of method usage and what can be considered emerging aspects of a theory of method usage in design.

3.3 Research Methods and Theory-Building

Different research methods contribute differently to each step of the theory-building process, which should ideally include both qualitative and quantitative, as well as analytical and empirical approaches (Cash, 2018; Wacker, 1998). Considering the vast amount of qualitative research within the field of design research and the aim of theory-building to establish relationships to make predictions about method usage, the empirical research presented in this dissertation generally takes a quantitative approach, utilising statistical analysis. The empirical studies also reflect pragmatism's overall emphasis on action and engagement with a phenomenon to build knowledge and understand it (see Dixon, 2020).

The mental processes of method usage are challenging to research since it is not directly observable, and the many factors influencing the processing are closely interrelated (Wallace, 2011). Operationalising the core components of the phenomenon of method usage as quantifiable constructs enables us to use statistical analysis to expand on the qualitatively described relationships between variables and identify patterns that might otherwise not be observable. The quantification of the central construct also allows us to make and test predictions. As such, this approach supports theory-building by translating complex, qualitative constructs of method usage—such as *design mindset* and *cognitive load*—into empirical data, facilitating deeper insights and generalisable conclusions that help advance the theory-building process. Statistical analysis also has the added benefit of allowing for greater objectivity and replicability, which is crucial within a phenomenon influenced by so many interrelated factors as method usage in design.

The methodological approaches of Inquiry I generally fit within what Wacker (1998) refers to as *empirical statistical research*. Following the process for inventory development laid out by Abell et al. (2009), the development of the *Design Mindset Inventory* (*D-Mindset0.1*) in Article I, utilises factor analysis, paired t-tests, and reliability testing to develop and validate the inventory, alongside regression analysis, to statistically examine relationships between *design mindset* and specific personality traits. Exploratory factor analysis is central to identifying distinct dimensions of the construct under development. The t-test and the regression analyses play a crucial role in establishing construct validity by showing how the construct of *design mindset* is related to existing constructs and aligns with design training. Reliability testing ensures that the construct is measured reliably and consistently.

Like Article I, Article II utilises t-tests and regression analysis to statistically examine the influence of different variables on the development of *design mindset*. The study presented in Article II is quasi-experimental, therefore also inhabiting elements of *empirical experimental research* (see Wacker, 1998). For example, in this study, an independent t-test is employed to test whether a significant change occurred from the pre- to the post-intervention measures, testing the overall hypothesis that *design mindset* is influenced by method usage. Similarly, the use of regression analyses is less exploratory in nature but rather utilised to test the assumed positive relationships to the independent variables.

From a theory-building perspective, the aim of *empirical statistical research* is to establish empirical support for the theoretical relationships (Wacker, 1998). However, in this case, the two articles of Inquiry I also contribute to the general development and conceptual understanding of *design mindset*.

The data collection for both Articles I and II was done using surveys (Appendix A and Appendix B). Article I utilises the pre-intervention questionnaire of the pre-post-intervention study presented in Article II as its foundation for developing and validating the *Design Mindset Inventory* (*D-Mindset0.1*), which in turn was the foundation for the statistical analysis in Article II. In addition to *D-Mindset0.1*, the questionnaire was built around the three well-established inventories of the General Self-Efficacy Scale (GSES; Schwarzer and Jerusalem, 1995), the Tolerance for Ambiguity Scale (TAS; Herman et al., 2010), and the Brief Sensation Seeking Scale (BSSS; Hoyle et al., 2002). All these inventories use Likert scales as their means of measuring the underlying construct. Compared to, e.g., yes/no questions, using Likert scales ensures richer data, thus helping to ensure the sensitivity and reliability of inventories (Abell et al., 2009).

Article III falls within *analytical conceptual research* (see Wacker, 1998). It uses an unstructured literature review and conceptual modelling to explore cognitive load as a lens for understanding design behaviour without empirical testing. This study contributes to the definition and relationship-building stages of theory-building, developing a theoretical framework to explain how *cognitive load* influences method usage and design activities. In doing so, Article III draws on existing theory on *cognitive load* to expand and modify it to use in relation to design and method usage. The conceptual model presented in this article lays the foundation for the empirical testing of Article IV, aligned with the process of theory-building (Cash, 2018; Wacker, 1998).

Article IV primarily falls within *empirical experimental research* (see Wacker, 1998). It presents a pilot study of an independent, single-anonymized, single-factor, three-level experiment, utilising the experimental control and statistical analysis in the form of ANCOVA's to determine the effect of using different types of design methods (independent variable) on the cognitive efficiency (dependent variable) of the method user. Once again, the data was collected using a survey, with the main component being the *NASA-TLX* (Hart, 2006; Hart & Staveland, 1988; NASA & Human Performance Research Group, n.d.). The *NASA-TLX* is by far the most used subjective measure of *cognitive load* (Hancock et al., 2021). In terms of theory-building, the goal of *empirical experimental research* is to provide empirical support for the conceptual framing and evidence for its predictive power. However, as a pilot study, the article also aims to contribute to the understanding of the study design and the implications of the underlying theoretical framing of the study.

4 Article I: Measuring Design Mindset

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

Jakob Clemen Lavrsen, Claus-Christian Carbon, and Jaap Daalhuizen

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 paper defines and operationalises 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 analysing a large sample of engineering students (N= 473). Using factor analysis, we identified four underlying factors of Design Mindset related to the theoretical concepts: Conversation with the Situation, Iteration, Co-Evolution of Problem-Solution, and Imagination. The latter part of the paper 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 Design Mindset, is both negatively and positively correlated. These relationships lend validity to the overall construct of Design Mindset and, by drawing on previously established relationships between the three personality traits and specific behaviours, 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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4.1 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 theorised to correlate with productive 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 & 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*)[3], which represents a foundational step in unravelling the interplay between designers and the design context by enabling the measuring 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 behaviours and strategies, and the broader design theory (e.g., Ball and Christensen, 2019; Cross, 1990, 2001; Dorst and Cross, 2001; Lawson and Dorst, 2009; Schön, 1983; Wynn and Clarkson, 2024), identifying values and beliefs guiding design practices, we develop and offer initial validation of the *Design Mindset Inventory* (*D-Mindset0.1*). The inventory is a crucial step towards 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,

[3] 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.

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.

4.2 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 & Govindarajan, 2002; Nelson & 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 (A. Buchanan, 2024).

4.2.1 Design Mindset

Building on the above description of mindset and the concept of a *method mindset,* connecting mindset and design practice (see Andreasen, 2003; Andreasen *et al.*, 2015; Daalhuizen *et al.*, 2014), 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 (Andreasen et al., 2015; Daalhuizen, 2014; Lawson, 2005; Wynn & Clarkson, 2024). In other words, *design mindset* is the mindset that aligns with effective design practices.

4.2.2 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.

4.2.2.1 Components of Design Mindset

Often, the concept of a *design mindset* has been structured around components like creative thinking, human-centredness, prototyping, visualisation, collaboration, optimism, self-efficacy, curiosity, risk-taking, ambiguity tolerance, empathy, openness, holistic thinking, to mention a few (see Blizzard *et al.*, 2015; Chesson, 2017; Dosi *et al.*, 2018; Howard *et al.*, 2015; Schweitzer *et al.*, 2016). 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-centredness, 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-centredness and collaborations to a defining aspect of being a designer, despite both being context-dependent and far from appropriate in all design situations. In the case of human-centredness, we even see a transition towards, for example, planet-centred design, including a significantly broader perspective of what is central in the design process, indicating that human-centredness is not an indisputable element of designing but perhaps more 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.

4.2.2.2 Mindset and behaviours

In a similar vein, most of the existing instruments for measuring *design mindset* tend to extrapolate mindset based on self-assessment of design-related behaviours 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 behaviour or assessment of appropriateness in the situation.

Schweitzer *et al.* (2016) recognise 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 behaviours is problematic since different mindsets might prompt similar behaviours in certain situations, making it hard to identify the underlying values. While mindset informs behaviours, assessing mindset based on specific behavioural 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 behavioural 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 behaviours as they relate to *design mindset*.

4.2.3 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 behaviours 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 utilise 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 such design-related characteristics as openness to new experiences, confidence in influencing the world around them, and a preference for complexity (Bandura, 1997; Dosi et al., 2018; Mahmoud et al., 2020; Zuckerman, 1979). 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 the *Design Mindset Inventory* (*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.

4.2.3.1 Self-Efficacy

Self-efficacy is not a generalised 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 behaviour, 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 endeavours 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 behaviours, 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.

4.2.3.2 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 (Dosi et al., 2018; Hassi & Laakso, 2011; Lawson & Dorst, 2009; Mahmoud et al., 2020). Similarly, *reflection in action*, a core concept of professional practice and central to our understanding of designing, is a 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 (Bandura, 1997; Runco, 2014; Simon, 1996).

4.2.3.3 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 (Hoyle et al., 2002; Zuckerman, 1979, 1994). People scoring high in *sensation-seeking* are likelier to engage in risky behaviours (Zuckerman & Aluja, 2015); they tend to underestimate the risk associated with their behaviours 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 & Amabile, 2010). There is always an element of risk associated with any creative endeavour (Runco, 2014). Creativity, by definition, requires novelty (Hennessey & Amabile, 2010; Weisberg, 2009). 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 towards openness to new experiences and perspectives (Franken, 2002; Hoyle et al., 2002). Their willingness to take risks enables them to go against norms and challenge the status quo (Zuckerman & Aluja, 2015). This inclination toward novelty and the uncharted 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 (McCrae, 1987; Zuckerman, 1979) and suggests that high sensation seekers are more inclined to find creative solutions to problems.

4.3 Method

To realise the goals of this article, we first develop an inventory to measure *design mindset* by operationalising conceptualisations from existing design theories about informed designers' strategies and behaviours. This process includes constructing items that capture the values and beliefs underlying such behavioural traits (see Section 4.4). 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 the *Design Mindset Inventory*, revealing four underlying factors (see Section 4.5). Drawing on design theory, we then recontextualise the items and name the four subconstructs of *D-Mindset0.1* (see Section 0).

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 4.7). These three personality traits have all been connected to creativity and behaviours 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 *design mindset* between two subgroups of the sample with known differences in levels of design education (see Section 4.8.1). McDonald's Omega (ω) was calculated to determine the internal consistency of *D-Mindset0.1* and its underlying factors (see Section 4.8.2).

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

4.3.1 Data Collection

All data were 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 the *Design Mindset Inventory* (*D-Mindset0.1*) introduced in this article, we utilised the General Self-Efficacy Scale (GSES; Schwarzer & Jerusalem, 1995), the Tolerance for Ambiguity Scale (TAS; Herman et al., 2010), and the Brief Sensation Seeking 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.

4.3.2 Participants

We recruited the participants for this study among 586 engineering students enrolled in the master's course Innovation in Engineering at the Technical University of Denmark (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, 2 participants (< 1%) chose the category 'other', and 2 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 specialisations (See Appendix C). While being a sample of convenience, based on the diversity of disciplinary specialisations, 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.

4.3.3 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.

4.4 Operationalising Design Mindset

At the core of operationalisation 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 behaviours 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 operationalise *design mindset*. It provides a structured overview of design behaviours. Furthermore, by distinguishing between naïve and *so*-called 'informed designers,' Crismond and Adams' (2012) matrix highlights the difference in the underlying values of the behavioural patterns between the two levels of expertise.

4.4.1 Generating Inventory Items

Crismond and Adams (2012) define nine design strategies representing core behavioural patterns displayed by designers (see Figure 4-1). Based on these design strategies and contrasting behavioural patterns, the first author generated a list of proto-items formulated as statements related to attitudes toward the strategies and associated behaviours. To avoid conflating mindset and behaviour, we opted for a format of agreement-to-value statements rather than behavioural self-assessments in formulating the items for the *Design Mindset Inventory*. 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).

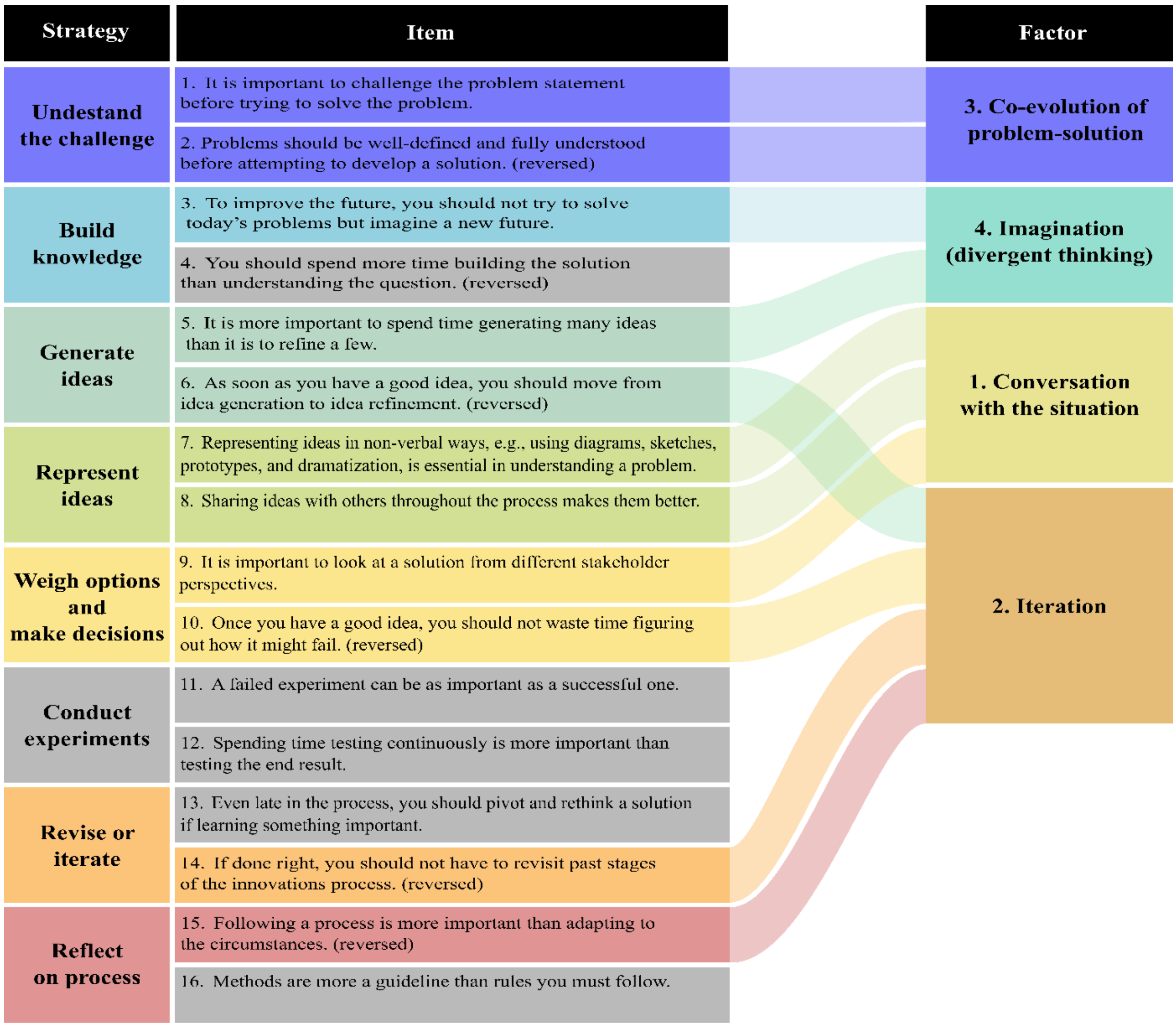

FIGURE 4-1: EVOLUTION OF THE DESIGN MINDSET INVENTORY

4.4.2 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.

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, reflecting the target population and prompting new iterations of refinement. Figure 4-1 contains the resulting list of items.

4.5 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 the *Design Mindset Inventory* (see Table 4-1). 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.

TABLE 4-1: 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 a guideline than rules you must follow.					0.907

Note. The applied rotation method is Promax.

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 4-1), 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 4-1, 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* 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 ten items in *D-Mindset0.1*.

4.6 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 4-1). 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.

4.6.1 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 4-1). 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*.

4.6.2 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 4-1). 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 (Daalhuizen, 2014; Schön, 1983; Simon, 1996) in which the externalisation of ideas plays a central role (Cross, 2001; Dove et al., 2018; Schön, 1983). 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 feedback for evaluating their actions and understanding of the context (Schön, 1983). Together, these re-combined items (see Figure 4-1) 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.

4.6.3 Factor 3: Co-Evolution of Problem-Solution

Factor 3 consists of Items 1 and 4 of the *Design Mindset Inventory* and combines items from the strategies *Understand the Challenge* and *Build Knowledge* (see Figure 4-1). Both items 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 & Cross, 2001). The co-evolution of the problem and solution space is central to design practice (Crilly, 2021; Dorst & Cross, 2001). Letting the understanding of the problem co-evolve with the solution enables the designer to suspend the decision on a solution (Crismond & Adams, 2012), learning through experimentation, reducing assumptions, and refining the understanding of the problem and what constitutes an appropriate solution (see Dorst, 2015; Dorst and Cross, 2001).

4.6.4 Factor 4: Imagination

Factor 4 combines Item 3 from the strategies *Build Knowledge* and Item 5 from *Generate Ideas* (see Figure 4-1). *Imagination* is one possible framing, encapsulating 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 optimised 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.

4.7 Assessing D-Mindset0.1 and its Subconstructs

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 4-2. 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 4-2.

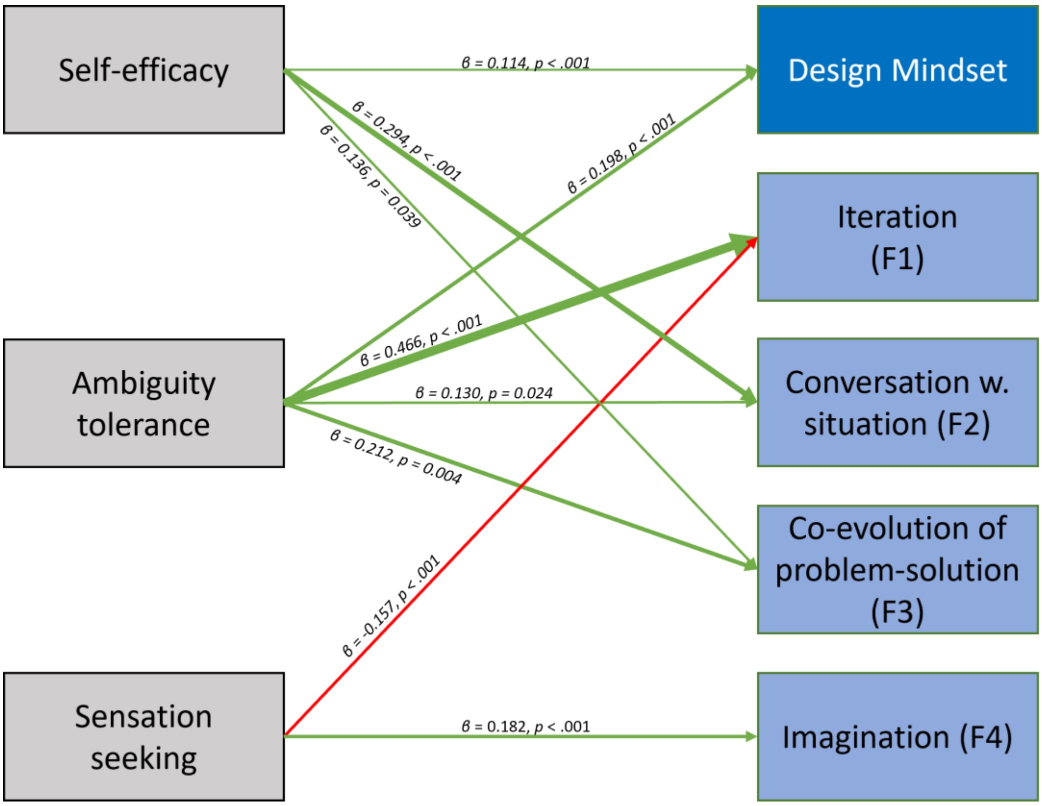

Figure 4-2: Relationship between independent and dependent variables

Table 4-2: Descriptive statistics

	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

4.7.1 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 Table 4-3, Table 4-4, and Table 4-5). 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 4-5). The model is statistically significant ($F(2, 470) = 26.5$, $p < .001$; see Table 4-4). 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 4-3). Both *ambiguity tolerance* ($b = 0.198$, $p < .001$) and *self-efficacy* ($b = 0.114$, $p < .001$) had a significant positive correlation with *D-Mindset0.1* (see Table 4-5), in line with our predictions. The coefficients (*b)* tell us that each time scores in *ambiguity tolerance* or *self-efficacy* increase by 1, *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 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.

Table 4-3: 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 4-4: 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 4-5: Coefficients - Design mindset

Model		Unstandardised (b)	SE	Standardised (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.

4.7.2 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. Analysing 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 4-7). *Ambiguity tolerance* was positively associated with individuals' scores on this factor ($b = 0.466$, $p < .001$; see Table 4-8), indicating that students with higher *ambiguity tolerance* scores tended to agree more with the items valuing iterative behaviours. *Sensation-seeking* also influences this factor significantly; however, its relationship is negative ($b = -0.157$, $p < .001$; see Table 4-8), 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 characterises 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 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 utilise 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 towards the diverse and sometimes conflicting behaviours associated with design in the design literature, where both working iteratively and taking risks are praised (Carlson et al., 2020; Grocott et al., 2019).

This regression model explained 6.8% of the variance in scores of *Iteration* in *D-Mindset0.1* (see Table 4-6).

TABLE 4-6: 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

TABLE 4-7: 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.

TABLE 4-8: COEFFICIENTS - ITERATION

							95% CI	
Model		Unstandardised (*b*)	SE	Standardised (*β*)	*t*	*p*	Lower	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.

4.7.3 Factor 2: Conversation with the Situation

The regression analysis for *Conversation with the Situation* (see Table 4-9, Table 4-10, and Table 4-11) 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 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 4-9).

Table 4-9: 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 4-10: 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.

Table 4-11: Coefficients - Conversation with the Situation

Model		Unstandardised (*b*)	SE	Standardised (*β*)	*t*	*p*	95% CI Lower	95% CI Upper
1	(Intercept)	6.031	0.037		163.347	< .001	5.96	6.10
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.

4.7.4 *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 4-13), 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 4-14). This model accounted for 3.6% of the variance in Factor 3 of *D-Mindset0.1* scores (see Table 4-12).

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, 2015; Dorst & Cross, 2001) and suspending final decisions about the solution (Crismond & 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 towards 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.

Table 4-12: 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

TABLE 4-13: 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 4-14: COEFFICIENTS - CO-EVOLUTION OF PROBLEM-SOLUTION

							95% CI	
Model		Unstandardised (*b*)	SE	Standardised (*β*)	*t*	*p*	Lower	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.

4.7.5 Factor 4: Imagination

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

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 (McCrae, 1987; Zuckerman, 1979), 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 4-15).

TABLE 4-15: 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

TABLE 4-16: 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.

TABLE 4-17: COEFFICIENTS - IMAGINATION

Model		Unstandardised	SE	Standardised	*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.

4.8 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.

4.8.1 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 4.4), 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 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 *D-Mindset0.1* scores than students from other programs with less design training. The average score across the ten 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.

4.8.2 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 *Design Mindset Inventory*, McDonald's Omega (ω) is 0.52 [95% CI 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) emphasised 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 operationalisation and exploration of *design mindset*.

TABLE 4-18: MCDONALD'S OMEGA

Factor		McDonald's Omega (ω)
1	Iteration	0.65 [CI95% 0.58..0.71]
2	Conversation with the Situation	0.65 [CI95% 0.54..0.74]
3	Co-Evolution of Problem-Solution	0.23 [CI95% 0.06..0.38]
4	Imagination	0.39 [CI95% 0.26..0.50]

Analysing the factors separately (see Table 4-18), we see Factors 1 and 2 have 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 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*.

4.9 Discussion

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

The *Design Mindset Inventory* constitutes a significant step towards assessing *design mindset* and investigating its relationship to other aspects of design practices. Despite the relatively low reliability of the inventory (see section 4.8.2), 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 4-1), where none of the original item pairs loaded into the same factor, highlights the interconnectedness of design behaviours and mindset. It shows the importance of distinguishing between mindset and behaviours to understand their relationship. Analysing the items of each factor revealed an alignment with design behaviours on a higher level of abstraction, connecting to high-level design theories as outlined in Section 0. 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 behaviours 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 the *Design Mindset Inventory*, 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.

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 behaviour, fostering more informed interventions and strategies within design education and practice, tailoring design methodologies to address individual shortcomings and optimise creative problem-solving within the design domain.

4.9.1 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 recognise 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 strategy *Troubleshoot* in constructing the inventory (see Section 4.4.2). The relatively low cumulative proportion of the total variance explained by the factors (see Section 4.5) 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 4-1) 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 towards 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 is, 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 rationalisation, 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, the *Design Mindset Inventory* 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 centre 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 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 generalisability and applicability of the *Design Mindset Inventory* across design domains.

Despite its shortcomings, the *D-Mindset0.1* takes a significant step towards operationalising 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.

4.10 Conclusion

This article has operationalised the construct of *design mindset* and developed the *Design Mindset Inventory* (*D-Mindset0.1*), allowing us to measure *design mindset*. The operationalisation revealed four underlying factors of *D-Mindset0.1—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 behaviours, 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 behavioural characteristics. The article also shows how operationalising constructs like *design mindset* can help further our understanding of core design concepts.

5 Article II: Developing Design Mindset

Developing Design Mindset: How individual and contextual factors influence the development of Design Mindset through Method Teaching

Jakob Clemen Lavrsen, Claus-Christian Carbon and Jaap Daalhuizen

Abstract:
Method Teaching is an essential approach for training novice designers to think and act like designers. Methods are commonly used in design education, yet with varying outcomes and experiences for students. There is a need to better understand how individual and contextual factors influence the effectiveness of Method Teaching. In this quasi-experimental pre-post-intervention study, we investigate how group composition, motivation, Design Mindset (D-Mindset0.1), Self-efficacy (GSES), Ambiguity tolerance (TAS), and Sensation-seeking (BSSS) influence students' learning through Method Teaching. Our results show that Method Teaching increases Design Mindset scores and that the effectiveness of Method Teaching is influenced significantly by the three personality traits and the level of prior Design Mindset.

Keywords: Design education; Method teaching; Design mindset; Personality traits

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5.1 Introduction

Design education is not merely about knowing facts; it emphasises ' … the importance of practical, embodied, and experiential ways of knowing and being, which are essential to the profession … ' (Shreeve, 2015, p. 83). Design methods can play a crucial role in facilitating this process, so much so that much design education is often structured around the training in, usage of, and reflection on design methods, in what has been termed *Method Teaching* (Daalhuizen et al., 2014). In *Method Teaching*, students are taught, through the practical use of design methods and reflection on the usage, to embody the behaviours and mindset associated with good design practice (Andreasen, 2003; Daalhuizen et al., 2014; Jones, 1992; Newstetter, 1998; Shreeve, 2015). However, due to the varying outcomes and experiences of students, several authors have questioned the effectiveness of design methods as teaching tools for training designers (Andreasen, 2003; Curry, 2014; Daalhuizen et al., 2014; Dorst, 2008; Jensen & Andreasen, 2010).

Method Teaching is a situated and highly contextual phenomenon (Curry, 2014; Daalhuizen & Hjartarson, 2022), entailing a complex interaction between method, method user, and context of use (Dorst, 2008; Hjartarson & Daalhuizen, 2021). Furthermore, method use is a skill in itself, influenced by individual differences, the context of use, and the learning situation (Andreasen, 2003; Curry, 2014; Daalhuizen & Hjartarson, 2022; Hjartarson & Daalhuizen, 2021), and is not straightforward to develop. Design education, and in particular *Method Teaching,* thus needs to develop the students' *Design Mindset* and support them in internalising the beliefs and attitudes that align with proper design practice. However, little is known about how different variables influence *Method Teaching* and the development of *Design Mindset*. In other words, we need a better understanding of the factors influencing learning and adoption of *Design Mindset* through method usage.

5.1.1 Research Question

Therefore, we ask:

> *How do individual and contextual factors influence the development of Design Mindset through Method Teaching?*

Starting from this question, we investigate the influence of the individual factors of *Design Mindset*, motivation, and the personality traits: *Self-efficacy, Ambiguity tolerance, and Sensation-seeking,* as well as context factors related to group composition, on the efficacy of *Method Teaching* in developing *Design Mindset* in students. In doing so, we aim to provide insight into the intricacies of developing *Design Mindset* through method usage and the factors influencing the process.

5.1.2 Hypotheses

Generally, we hypothesise that *Design Mindset* develops through *Method Teaching*. Additionally, following our research question, we have identified ten variables related to individual and contextual factors: initial *Design Mindset* scores, *Sensation-seeking, Self-efficacy, Ambiguity tolerance, Excited about course, Will use tools, Gender ratio in group, Facilitator ratio in group, Avg. Design Mindset score in group,* and *Avg. facilitator Design Mindset in group,* which we hypothesise will positively impact the learning outcome as represented by positive changes in *Design Mindset*. The proposed relationship between the variables is illustrated in Figure 5-1.

The following sections provide the theoretical foundations and the overall argument for the relevance and inclusion of the variables.

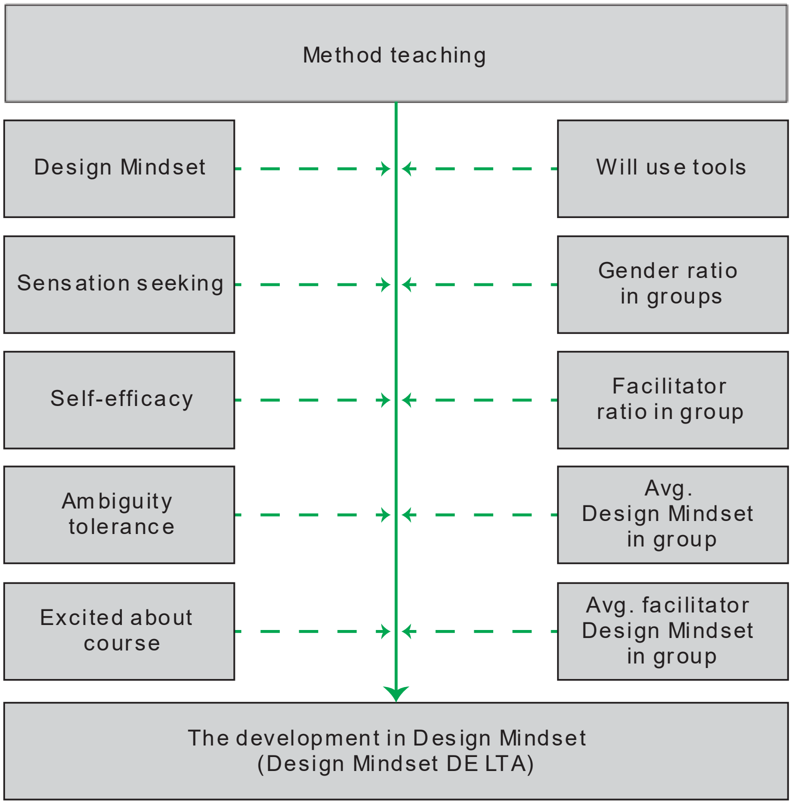

Figure 5-1 Interaction between Method Teaching (intervention) and the variables hypothesised to influence the development of Design Mindset (dependent variable).

5.2 Understanding Method Teaching

Design methods play two central roles in *Method Teaching*. Firstly, design methods are central to structuring the learning situation by scaffolding the project/problem-based and cooperative learning (Royalty, 2018). Secondly, design methods function as exemplars of design practice, guiding students' behaviours and, through usage, helping students to embody a *Design Mindset* (Cross, 2008).

5.2.1 Scaffolding the Learning Situation

Projects are an essential source of learning for designers (Lawson & Dorst, 2009). Design methods provide a structure to projects and the underlying activities in *Method Teaching* (Curry, 2014; Daalhuizen et al., 2014; Hjartarson & Daalhuizen, 2021; Lawson & Dorst, 2009; Newstetter, 1998; Royalty, 2018). They help students break down the project into specific activities by stringing methods together into a design process (Cross, 2008; Gericke et al., 2020), thus structuring the learning situation, reducing uncertainty, and making projects more manageable (Curry, 2014). Scaffolding the learning situation supports improved performance and promotes learning (Newstetter, 1998), and enabling the students to handle a project that matches the complexity of real-world design problems without paralysing them and stifling their learning (see Sulman, 2005).

As is the case with any educational scaffolding (see Savery, 2006), the aim of *Method Teaching* is not to teach the students to use the methods but rather to teach them to think and act like designers so that the scaffolding can be removed over time.

5.2.2 Method Usage and Mindset

Design methods have been defined as ' … formalised representation of a design activity that functions as a mental tool to support designer to (learn how to) achieve a certain goal, in relation to certain circumstances and resources available*'* (Daalhuizen et al., 2019, p. 37). As such, design methods are carriers of procedural knowledge (Blessing & Chakrabarti, 2009; Cantamessa, 2003; Daalhuizen & Cash, 2021).

However, method usage is not straightforward. Mindlessly following prescribed procedures does not guarantee a good design solution (Curry, 2014; Daalhuizen et al., 2014). Method users have to interpret and assess the appropriateness of a method in their specific situation, taking into consideration, e.g. the overall goal of the project, the stage in the design process, the social organisation of the project team, and other stakeholders in the project (Badke-Schaub et al., 2011; Daalhuizen & Hjartarson, 2022; Gericke et al., 2016; Lavrsen et al., 2022; Newstetter, 1998).

Ideally, a design method contains all the necessary information for implementation (Daalhuizen & Cash, 2021; Jagtap et al., 2014). However, knowledge essential for correct implementation is often implicit or omitted in the formalisation of methods (Jänsch et al., 2005). Furthermore, methods are often removed from their original context of use and the experiential knowledge of using them (Andreasen, 2003; Dorst, 2008; Hjartarson & Daalhuizen, 2021; Johansson-Sköldberg et al., 2013). Even if the method contains the necessary information, the user has to understand it and recognise its affordance in achieving their goal (Newstetter, 1998).

Consequently, the effective use of design methods requires an alignment between the method and the method user's experience, values, and beliefs (Andreasen, 2003; Andreasen et al., 2015; Daalhuizen & Cash, 2021); a so-called *method mindset* (Daalhuizen et al., 2014). A method mindset includes the knowledge and experiences required to effectively employ a method and, ultimately, preferences for one method over alternatives (Daalhuizen et al., 2014).

While mindset influences how tasks, contexts, and methodology are interpreted and understood in relation to one another (Andreasen et al., 2015), it is worth noting that method usage also shapes the development of mindsets. Design methods act as mental tools, stimulating designerly thinking and behaviours (Cross, 2008; Daalhuizen & Hjartarson, 2022), helping students to behave as professionals (Royalty, 2018), and embody good practice (Andreasen, 2003; Daalhuizen et al., 2014; Jones, 1992; Shreeve, 2015; Sulman, 2005). This is reflected by the tendency of more experienced designers to rely less on formalised methods as procedural knowledge becomes internalised and behaviours embodied (Hjartarson & Daalhuizen, 2021; Lavrsen et al., 2022; Lawson & Dorst, 2009).

Transcending method usage and delving into design practice more generally, what we have referred to as *Design Mindset* is the mindset that aligns with the beliefs, attitudes, norms, and practices of appropriate and efficient design practice (Lavrsen et al., 2023, in press). In the context of *Method Teaching*, the development of *Design Mindset* can thus be seen as the core learning outcome (see Figure 5-2).

5.2.3 Learning through Method Usage

Experiential learning theory holds that learning occurs in a cycle of experience, reflection, conceptualisation, and experimentation (A. Y. Kolb & Kolb, 2022; D. A. Kolb, 2015). In *Method Teaching*, this learning cycle is facilitated by using design methods, as shown in Figure 5-2. Design methods inform the concrete experience of designing by imposing an initial structure to the design context and providing guidance on how to behave and act in that context.

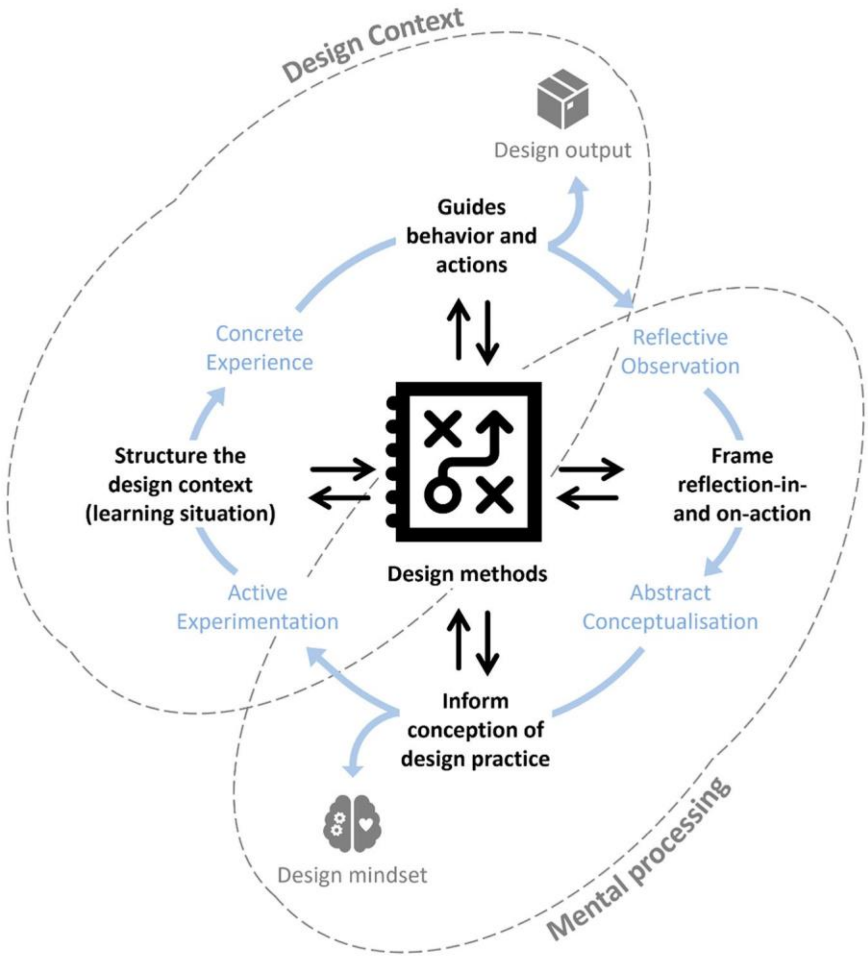

FIGURE 5-2: METHOD TEACHING: HOW DESIGN METHODS INFORM THE EXPERIENTIAL LEARNING PROCESS.

As an exemplar of design practice, the methods also inform the reflective process necessary for translating experiences into learning. Schön (1983) distinguishes between *reflection-in-action* and *reflection-on-action*. Design methods function as a reference for reflection-in-action in the design process and retrospectively as a reference for reflection-on-action (Hjartarson & Daalhuizen, 2021). They provide a baseline for making sense of the situation and design activities in relation to it. The reflective process is usually triggered by encountering something unexpected or getting stuck (A. Y. Kolb & Kolb, 2022). Here, prior experiences, theoretical knowledge, and the method's portrayal of design practice are considered to reevaluate the students' understanding of the situation and make sense of it. New conceptualised insights can then be tested and refined through experimentation, for example, by tweaking the method's implementation or trying another, more promising method. If the new conceptualisation improves the understanding or control over a situation, it can become part of how learners think and act (D. A. Kolb, 2015). Through this process, unique approaches to solving design problems can be developed (Lawson & Dorst, 2009).

5.2.4 Group Competencies and Composition

Like other forms of project-based learning, *Method Teaching* relies on cooperative learning (see Johnson et al., 2014). Designing, as well as design learning, is a social process shaping both the learning outcomes and the context of learning (Newstetter, 1998). In *Method Teaching*, learning happens as the students engage with the problem, the methods, and each other. Leveraging each other's knowledge, insights, and unique expertise, the students work together to solve the problem and learn collaboratively. When the students negotiate their understanding of the problem, what they need to do, what methods to use, and how to use them, they share their knowledge, opinions, and perspectives, enhancing their learning opportunities (Hjartarson & Daalhuizen, 2021; Johnson et al., 2014; Scager et al., 2016). More diverse groups can stimulate a more nuanced reflection in the group, which is central to the learning process and professional practice (Hjartarson & Daalhuizen, 2021; Scager et al., 2016; Schön, 1983). Furthermore, more experienced students can help the group make more appropriate use of methods and increase the chances of a positive experience using them (Daalhuizen &

Hjartarson, 2022; Johnson et al., 2014; Lavrsen et al., 2022; E. B.-N. Sanders & Stappers, 2008). In this study, the groups were secured some design methods and processes expertise through student facilitators, who are tasked with facilitating the overall teamwork and the use of the specific methods (see Section 5.3.2).

Based on the role of diversity in group-based learning, we hypothesise that having a higher ratio of females in the otherwise male-dominated groups (*Gender ratio in group*) will positively influence changes in *Design Mindset*. We also hypothesise that having more facilitators in a group (*Facilitator ratio in group*) will increase learning by providing extra experience with and support in applying design methods. Similarly, we hypothesise that higher *Design Mindset* scores of the facilitators (*Avg. facilitator Design Mindset in group*) and the groups overall (*Avg. Design Mindset score in group*) will positively influence the group members learning.

5.2.5 The Student and Individual Differences

As already established, individual differences and preferences influence the experience and effectiveness of method usage and learning and, thus, the effects of *Method Teaching*. In this section, we outline some of the individual factors that might influence the learning outcomes of *Method Teaching*.

5.2.5.1 Motivation

Engagement in the learning situation is dependent on the student's motivation. Motivation determines the extent to which individuals engage in the learning process, persist in facing challenges, and seek learning opportunities (Bandura, 1997; Zimmerman et al., 1992). Motivation is influenced by how a situation is interpreted, which again depends on several factors, including personality traits. Generally, there are two types of motivation: intrinsic and extrinsic. In an educational context, intrinsically motivated students are motivated by the task itself, while extrinsically motivated students are motivated by the reward or grade (Scager et al., 2016). Structural factors like group interdependence, autonomy, and the challenge of the assignment also influence motivation (Scager et al., 2016).

Consequently, we hypothesise a positive relationship between the changes in *Design Mindset* and the variables related to excitement about the course (*Excited about course*) and the perceived usefulness of the course (*Will use tools*).

5.2.5.2 Ambiguity Tolerance

Most design situations can be described as ambiguous (Mahmoud et al., 2020). Ambiguous situations ' … cannot be adequately structured or categorised by the individual because of the lack of sufficient cues' (Budner, 1962, p. 30). *Ambiguity tolerance* determines whether ambiguous situations are perceived as desirable or threatening (Budner, 1962) and how one responds to them (Furnham & Marks, 2013). Low tolerance for ambiguity tends to be expressed in a ' … tendency to view ambiguous situations rigidly in black or white' (Rosen et al., 2014, p. 62), rejection and avoidance of such situations (Budner, 1962; Furnham & Marks, 2013; Rosen et al., 2014), and emotional reactions such as uneasiness, discomfort, dislike, anger, and anxiety (Rosen et al., 2014). On the other end of the spectrum, a high tolerance for ambiguity is associated with creativity—even though the evidence for the connection might be weaker than theoretically or intuitively expected (Merrotsy, 2013).

Based on the high levels of ambiguity generally associated with designing (Cash & Kreye, 2017, 2018; Cross, 1990; Lawson & Dorst, 2009; Mahmoud et al., 2020), we hypothesise that higher *ambiguity tolerance* will allow the students to engage more broadly with both the ambiguities of the design context and the general learning situation, resulting in improved *Design Mindset* scores.

5.2.5.3 Sensation-Seeking

Like *Ambiguity tolerance, Sensation-seeking* relates to individual reactions to the world around them. *Sensation-seeking* is ' … defined by the seeking of varied, novel, complex, and intense sensations and experiences, and the willingness to take physical, social, legal, and financial risks for the sake of such experience' (Zuckerman, 1994, p. 27). Risky behaviours are likelier among people scoring high in *Sensation-seeking*, who tend to underestimate the risk associated with their behaviours and, therefore, are also more likely to repeat them (Hoyle et al., 2002). They are, however, not risk-seekers (Zuckerman, 1994).

Sensation seekers engage in new situations with openness (Franken, 2002; Hoyle et al., 2002). Furthermore, high sensation seekers are prone to divergent thinking (Zuckerman, 1994), which Crismond and Adams (2012) identified as an indicator of informed design practice and Guilford (1968) as a necessity for generating creative ideas.

Consequently, we hypothesise that scoring higher on *Sensation-seeking* will lead to an improved *Design Mindset*, as the openness to new and complex situations and willingness to take risks should result in a willingness to investigate and challenge both the design context and the methods used, facilitating more opportunities for reflection and learning.

5.2.5.4 Self-Efficacy

Self-efficacy is the belief in one's ability to handle a situation (Bandura, 1997). Like the other personality traits presented above, *Self-efficacy* influences people's behaviour. *Self-efficacy*:

> … *influence the courses of action people choose to pursue, how much effort they put forth in given endeavors, how long they will persevere in the face of obstacles and failures, their resilience to adversity, whether their thought patterns are self-hindering or self-aiding, how much stress and depression they experience in coping with taxing environmental demands, and the level of accomplishment they realize* (Bandura, 1997, p. 3).

Consequently, *Self-efficacy* influences learners' engagement, effort, and goal-setting behaviour. People scoring high in *Self-efficacy* tend to take a future perspective, set bigger goals, and work harder to make them a reality (Bandura, 1997), and generally display what Kelley and Kelley (2013) call creative confidence (Jobst et al., 2012). As such, we hypothesise that higher scores in *Self-efficacy* translate into improved learning outcomes and higher scores in *Design Mindset*.

5.2.5.5 Design Mindset

Lastly, we hypothesise that individual differences in *Design Mindset* influence the effectiveness of *Method Teaching*. Like the *Design-Mindset-based* group variables, we associate individual *Design Mindset* with design-related competencies. Based on its recent operationalisation as a construct (Lavrsen et al., 2023, in press), we have a limited basis for predicting its influence on the learning outcome of *Method Teaching*. However, based on the expectation that existing competencies might facilitate the navigation of the design context and learning situation, we hypothesise that higher *Design Mindset* scores (*T1_Design Mindset*) will positively influence the learning outcome.

5.3 Method

This study employs a quasi-experimental pre–post-intervention research design to answer our research questions and investigate how key variables influence the effectiveness of *Method Teaching*. The quasi-experimental format was chosen to reflect the real-life learning context, using an existing course—designed around *Method Teaching*—as the intervention (see Section 5.3.2). Data was collected employing a questionnaire before (T1) and towards the end of the course project (T2). The pre-intervention data (T1) has been employed and discussed in previous research (Lavrsen et al., 2023, in press), reporting the development of the inventory used to measure *Design Mindset* for this study (see Section 5.3.3.1).

5.3.1 Sample

We recruited our participants from a sample of 586 engineering students enrolled in a design and innovation course mandatory for all master students at Technical University Denmark (DTU). The students were asked to fill in the questionnaires as part of the course but had the option not to have their data used for the study. Four hundred seventy-three completed the pre-intervention questionnaire; of those, 254 completed both the pre- and post-intervention questionnaire, resulting in a response rate of 43%. Of the final sample, 150 (59%) identified as male, 101 (40%) as female, 2 (1%) as other, and 1 opted not to answer.

The participants' backgrounds varied between more than thirty different engineering educations (see Appendix D), with varying degrees of training (*M* = 1.8 courses; *Md* = 1; *SD* = 2.42) and practical work experience (*M* = 3.7 months; *Md* = 0; *SD* = 7.17), with the majority having little to no training or experience with innovation. The age ranged from 20 to 41 years, with an average age of 24.4 years (*SD* = 2.54).

Despite being a sample of convenience, the diversity of disciplinary specialisations in engineering and different levels of exposure to design and innovation theory and practice make the sample representative of engineering students.

5.3.2 Procedure

We studied *Method Teaching* in the context of two intertwined project-based full-time courses that ran over three weeks. One course aimed at giving students innovation competencies through participation in an innovation project as part of a team. The other focused on facilitating the innovation process for the students in the innovation course to teach facilitation skills. Despite different learning objectives, the overall structure for both courses was the same, and it was, in practice, taught as one.

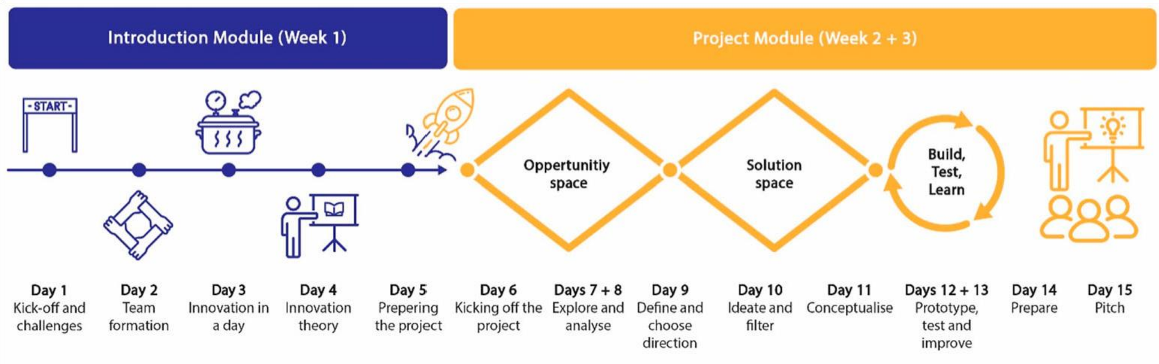

FIGURE 5-3: THE MODULES AND SETUP OF THE COURSE.

The courses consisted of a one-week introduction module and a two-week project module (see Figure 5-3). The introduction module included an introduction to innovation and design processes, methods, mindset, real-world innovation challenges for the project phase, and team formation. To ensure multidisciplinary teams, the project teams were formed based on the students' case preferences and disciplinary specialisations. The teams consisted of six to ten innovators and one or two facilitators. Four broad cases, including overall challenges and problems, were presented by industry partners. They were centred around: securing renewable carbon for the chemical sector, climate and environmentally-friendly solutions for the maritime industry, sustainable retail focusing on keeping local retail areas relevant and environmentally friendly, and how to make access to nature available for people with cognitive disabilities.

The project module was structured around a predefined and controlled design process based on the double-diamond process (Design Council, 2003), including planning and preparation, exploration and research, definition of innovation challenge, ideation, conceptualisation, prototyping and testing, and pitching (see Figure 5-3).

Students were guided through the design process through scaffolded design activities structured around design methods like *User Observation*, *List of Requirements*, *Weighted Objectives*, and *10 plus 10 Ideation* (van Boeijen et al., 2020), and with specific deliverables most days. Within the limits of this structured design process, the facilitators were free to bring in additional methods to support the completion and quality of the deliverables. Two of the authors were involved in the course's development and teaching.

5.3.3 Measurements and Data Collection

We administered two questionnaires: one at the beginning of the course (Day 2; Appendix A, previously published in Lavrsen et al. (in press) and one after completing the project module of the course (Day 14; see Appendix B). The questionnaires consisted of four main parts, with instruments measuring *Design Mindset*, *Self-efficacy*, *Ambiguity tolerance*, and *Sensation-seeking*. In addition, the pre-intervention questionnaire included items related to consenting to participate, demographic information, motivation, and experience. As such, the pre-intervention questionnaire consisted of 60 items, and the post-questionnaire consisted of 50.

5.3.3.1 Design Mindset

To measure the learning outcome, we developed the *Design Mindset Inventory* (*DMindset0.1*; Lavrsen et al., 2023, in press) to measure *Design Mindset*. *D-Mindset0.1* consists of 10 items, all measured on a 7-point Likert scale, ranging from *strongly disagree* (= 1) to *strongly agree* (= 7), and can be divided into four underlying factors: (1) *Iteration*, (2) *Conversation with the situation*, (3) *Co-evolution of problem-solution*, and (4) *Imagination* (Lavrsen et al., in press). Based on the pre-and post-intervention scores of *Design Mindset*, we calculated the changes in *Design Mindset* (*Design Mindset_DELTA*) as a measure of learning outcomes (see Figure 5-2).

5.3.3.2 Personality Traits

We used the General Self-efficacy Scale (GSES; Schwarzer & Jerusalem, 1995) to measure *Self-efficacy*. We modified the GSES from a 5-point to a 7-point Likert scale to align it with the other instruments used in the questionnaire and increase the usability of the entire set of employed scales.

We have used the 12-item Tolerance for Ambiguity Scale (TAS; Herman et al., 2010) to measure *Ambiguity tolerance*. Despite initially being designed for cross-cultural research, the TAS has previously been used in connection with design research by Mahmoud et al. (2020).

We used the Brief Sensation Seeking Scale (BSSS; Hoyle et al., 2002) to measure *Sensation-seeking*. The BSSS is based on the widely used Sensation Seeking Scale-V (SSS-V; Zuckerman et al., 1978), but BSSS has the advantage of only consisting of eight items rather than 40 and using the more user-friendly Likert scale as a response format rather than the forced-choice format (Hoyle et al., 2002).

5.4 Analysis and Results

In the following section, we examine the descriptive statistics of the variables, the assessment of the employed *t*-test, the regression analyses, and the evaluation of the resulting models.

5.4.1 Data Processing

Before conducting the analysis, the data was cleaned. Due to the consent form only being part of the pre-invention questionnaire, fifty participants who only responded to the post-intervention questionnaire were removed from the dataset. While a loss of data, these responses would not have been useful for this study due to them missing the preintervention responses and, thus, the grounds for comparison of the development in *Design Mindset*. Incomplete entries were also removed. A few participants answered the post-questionnaire twice. We removed their second entry to avoid duplicates and bias.

5.4.2 Descriptive Statistics

Table 5-1 shows the descriptive statistics for the dependent and the independent variables. It is worth noting that some variables rely on smaller sample sizes. The biggest difference in sample size is between pre- and post-intervention-based variables (n_{Pre} = 473; n_{Post} = 254), reflecting a lower response rate for the post-intervention questionnaire than the pre-intervention questionnaire. The group-based variables (*Gender ratio in group* and *Avg. Design Mindset score in group*) are also based on a smaller sample since these variables could only be calculated for respondents in groups where all members participated in the study.

While a Shapiro–Wilk test indicates that the majority of our data is not normally distributed ($p < .05$), our large sample size means that most can be considered so according to Kim's (2013) guidelines ($n < 50$: absolute *z*-scores for both skewness and kurtosis < 1.96; $50 < n < 300$: absolute *z*-scores for both skewness and kurtosis < 3.29; $n > 300$: absolute Skewness < 2 and absolute Kurtosis < 7; see Table 5-1). The exceptions are *T2_Conversation with the situation (F2), Gender ratio in group, Avg. Design Mindset score in group*, and all the dependent variables except *Co-evolution of problem-solution (F3)_DELTA*. While this influences the reliability of the regression analysis presented later, we consider the analysis robust enough to provide meaningful results.

5.4.3 The Changes in Design Mindset

The descriptive statistics (Table 5-1) clearly show an increase in *Design Mindset* from the pre- (*M* = 4.41, *SD* = 0.53) to the post-intervention test (*M* = 4.55, *SD* = 0.59). To test if this increase was significant, we conducted paired sample *t*-tests for *Design Mindset* and each of its sub-constructs: *Iteration*, *Conversation with the situation*, *Co-evolution of problem-solution*, and *Imagination*.

The *t*-tests (Table 5-2) revealed that the increase in *Design Mindset* was significant, $t(253) = -3.66$, $p < .001$, Cohen's $d = 0.230$, supporting our hypothesis of *Method Teaching* positively influencing *Design mindset*.

Of the *Design Mindset* sub-constructs, only *Imagination,* $t(253) = -7.93$, $p < .001$, Cohen's $d = -0.498$, shows a significant increase in score from the pre- to the postintervention test, indicating that it is the primary driver of the increase in *Design Mindset* scores. While the remaining sub-constructs show no significant changes, it is worth noting that *Iteration* decreased from the pre- to the post-intervention test as the only construct. Both significant results—*Design Mindset* and *Imagination*—fall within what can be considered a medium effect size (0.2 < *Cohen's d* < 0.8; (Cohen, 2013).

TABLE 5-1: DESCRIPTIVE STATISTICS OF ALL VARIABLES AT T1 AND T2, INCLUDING INDEPENDENT AND DEPENDENT VARIABLES

		Valid	*Median*	*Mean*	*SD*	Skewness	*z*(Skewness)	Kurtosis	*z*(Kurtosis)	Min.	Max.
T1 scores	T1_Design Mindset	473	4.45	4.41	0.5	0.034	0.304	0.382	1.705	2.4	6.1
	T1_Iteration	473	4.75	4.75	1.0	−0.562	−5.018	0.711	3.174	1.0	7.0
	T1_Conversation with the situation	473	6.00	6.03	0.8	−0.960	−8.571	1.970	8.795	1.5	7.0
	T1_Co-evolution of problem-solution	473	5.00	4.97	1.0	−0.075	−0.670	−0.129	−0.576	2.5	7.0
	T1_Imagination	473	3.50	3.74	1.1	0.117	1.045	−0.020	−0.089	1.0	7.0
T2 scores	T2_Design Mindset	254	4.55	4.55	0.6	−0.184	−1.203	−0.263	−0.865	2.8	6.1
	T2_Iteration	254	5.00	4.78	1.0	−0.474	−3.098	−0.050	−0.164	1.5	7.0
	T2_Conversation with the situation	254	6.50	6.12	0.9	−1.033	−6.752	0.357	1.174	3.5	7.0
	T2_Co-evolution of problem-solution	254	5.00	5.03	1.0	−0.218	−1.425	0.012	0.039	1.5	7.0
	T2_Imagination	254	4.50	4.29	1.1	−0.208	−1.359	−0.224	−0.737	1.0	7.0
Dependent variables	Design Mindset_DELTA	254	0.18	0.13	0.6	−0.389	−2.542	1.203	3.957	−1.8	1.9
	Iteration_DELTA	254	0.00	-0.02	1.0	−1.077	−7.039	3.803	12.510	−5.0	2.3
	Conversation with the situation_DELTA	254	0.00	0.08	0.9	−1.062	−6.941	2.093	6.885	−3.5	2.0
	Co-evolution of problem-solution_DELTA	254	0.00	0.06	1.2	−0.385	−2.516	0.958	3.151	−3.5	4.0
	Imagination_DELTA	254	0.50	0.59	1.2	0.095	0.621	1.080	3.553	−3.0	5.0
Independent variables	Sensation-seeking	473	4.38	4.35	1.2	−0.082	−0.732	−0.637	−2.844	1.4	7.0
	Self-efficacy	473	5.20	5.18	0.7	−0.299	−2.670	0.681	3.040	2.0	7.0
	Ambiguity tolerance	473	4.50	4.46	0.6	−0.176	−1.571	0.154	0.688	2.2	6.1
	Excited about course	473	5.00	4.73	1.5	−0.519	−4.634	−0.323	−1.442	1.0	7.0
	Will use tools	473	6.00	5.35	1.3	−0.716	−6.393	0.169	0.754	1.0	7.0
	Gender ratio in group	68	0.23	0.28	0.2	0.241	0.828	−1.389	−2.420	0.0	0.6
	Facilitator ratio in group	464	0.11	0.13	0.0	1.823	16.133	2.228	9.858	0.1	0.2
	Avg. Design Mindset score in group	117	4.42	4.44	0.2	−0.268	−1.196	−0.972	−2.189	4.1	4.8
	Avg. facilitator Design Mindset in group	456	4.73	4.76	0.5	−0.142	−1.246	−0.358	−1.570	3.6	5.6

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

TABLE 5-2: PAIRED SAMPLE T-TEST

Measure 1		Measure 2	t	df	p	M_{Δ}	SE Difference	Cohen's d	SE Cohen's d	95% CI for Cohen's d: Lower	95% CI for Cohen's d: Upper
T1_Design Mindset	–	T2_Design Mindset	−3.66	253	< .001***	−0.128	0.035	−0.230	0.065	−∞	−0.125
T1_Iteration	–	T2_Iteration	0.29	253	0.615	0.018	0.061	0.018	0.061	−∞	0.121
T1_Conversation with the situation	–	T2_Conversation with the situation	−1.40	253	0.082	−0.081	0.058	−0.088	0.069	−∞	0.016
T1_Co-evolution of problem-solution	–	T2_Co-evolution of problem-solution	−0.87	253	0.193	−0.063	0.073	−0.054	0.073	−∞	0.049
T1_Imagination	–	T2_Imagination	−7.93	253	< .001***	−0.594	0.075	−0.498	0.070	−∞	−0.388

Note. The alternative hypothesis specifies that Measure 1 is less than Measure 2 for all tests. For example, T1_Design Mindset is less than T2_Design Mindset.
Note. Student's *t*-test.
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

TABLE 5-3: MODEL SUMMARIES—INDIVIDUAL VARIABLES

	Model	R	R^2	Adjusted R^2	RMSE	R^2 Change	F Change	$df1$	$df2$	p
T1_Design Mindset	H_0	0.000	0.000	0.000	0.559	0.000		0	253	
	H_1	0.370	0.137	0.134	0.520	0.137	40.08	1	252	< .001***
Sensation-seeking	H_0	0.000	0.000	0.000	0.559	0.000		0	253	
	H_1	0.080	0.006	0.002	0.558	0.006	1.60	1	252	0.207
Self-efficacy	H_0	0.000	0.000	0.000	0.559	0.000		0	253	
	H_1	0.164	0.027	0.023	0.552	0.027	6.97	1	252	0.009**
Ambiguity tolerance	H_0	0.000	0.000	0.000	0.559	0.000		0	253	
	H_1	0.233	0.054	0.051	0.544	0.054	14.46	1	252	< .001***
Excited about course	H_0	0.000	0.000	0.000	0.559	0.000		0	253	
	H_1	0.005	0.000	-0.004	0.560	0.000	0.01	1	252	0.932
Will use tools	H_0	0.000	0.000	0.000	0.559	0.000		0	253	
	H_1	0.118	0.014	0.010	0.556	0.014	3.55	1	252	0.061
Gender ratio in group	H_0	0.000	0.000	0.000	0.577	0.000		0	48	
	H_1	0.175	0.031	0.010	0.574	0.031	1.49	1	47	0.228
Facilitator ratio in group	H_0	0.000	0.000	0.000	0.560	0.000		0	251	
	H_1	0.088	0.008	0.004	0.559	0.008	1.96	1	250	0.163
Avg. Design Mindset score in group	H_0	0.000	0.000	0.000	0.577	0.000		0	48	
	H_1	0.193	0.037	0.017	0.572	0.037	1.82	1	47	0.184
Avg. facilitator Design Mindset in group	H_0	0.000	0.000	0.000	0.584	0.000		0	159	
	H_1	0.074	0.006	-0.001	0.584	0.006	0.88	1	158	0.351

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

TABLE 5-4: ANOVA–INDIVIDUAL VARIABLES

Model			Sum of Squares	*df*	Mean Square	*F*	*p*
T1_Design Mindset	H_1	Regression	10.8	1	10.8	40.1	< .001***
		Residual	68.2	252	0.3		
		Total	79.0	253			
Sensation-seeking	H_1	Regression	0.5	1	0.5	1.6	0.207
		Residual	78.5	252	0.3		
		Total	79.0	253			
Self-efficacy	H_1	Regression	2.1	1	2.1	7.0	0.009**
		Residual	76.9	252	0.3		
		Total	79.0	253			
Ambiguity tolerance	H_1	Regression	4.3	1	4.3	14.5	< .001***
		Residual	74.7	252	0.3		
		Total	79.0	253			
Excited about course	H_1	Regression	0.0	1	0.0	0.0	0.932
		Residual	79.0	252	0.3		
		Total	79.0	253			
Will use tools	H_1	Regression	1.1	1	1.1	3.6	0.061
		Residual	77.9	252	0.3		
		Total	79.0	253			
Gender ratio in group	H_1	Regression	0.5	1	0.5	1.5	0.228
		Residual	15.5	47	0.3		
		Total	16.0	48			
Facilitator ratio in group	H_1	Regression	0.6	1	0.6	2.0	0.163
		Residual	78.2	250	0.3		
		Total	78.8	251			
Avg. Design Mindset score in group	H_1	Regression	0.6	1	0.6	1.8	0.184
		Residual	15.4	47	0.3		
		Total	16.0	48			
Avg. facilitator Design Mindset in group	H_1	Regression	0.3	1	0.3	0.9	0.351
		Residual	53.9	158	0.3		
		Total	54.2	159			

Note. The intercept model is omitted, as no meaningful information can be shown.
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Table 5-5: Coefficients—individual variables

	Model		Unstandardised	Standard Error	Standardised	*t*	*p*
T1_Design Mindset	H_0	(Intercept)	0.127	0.035		3.635	< .001 ***
	H_1	(Intercept)	2.006	0.299		6.720	< .001 ***
		T1_Design Mindset	-0.425	0.067	-0.370	−6.331	< .001 ***
Sensation-seeking	H_0	(Intercept)	0.127	0.035		3.635	< .001 ***
	H_1	(Intercept)	0.291	0.134		2.176	0.030 **
		Sensation-seeking	0.037	0.029	-0.080	−1.266	0.207
Self-efficacy	H_0	(Intercept)	0.127	0.035		3.635	< .001 ***
	H_1	(Intercept)	−0.514	0.245		−2.094	0.037 **
		Self-efficacy	0.120	0.045	0.164	2.640	0.009 **
Ambiguity tolerance	H_0	(Intercept)	0.127	0.035		3.635	< .001 ***
	H_1	(Intercept)	−0.768	0.238		−3.228	0.001 ***
		Ambiguity tolerance	0.197	0.052	0.233	3.803	< .001 ***
Excited about course	H_0	(Intercept)	0.127	0.035		3.635	< .001 ***
	H_1	(Intercept)	0.117	0.123		0.955	0.340
		Excited about course	0.002	0.025	0.005	0.086	0.932
Will use tools	H_0	(Intercept)	0.127	0.035		3.635	< .001 ***
	H_1	(Intercept)	0.408	0.153		2.668	0.008 **
		Will use tools	−0.052	0.028	-0.118	−1.884	0.061
Gender ratio in group	H_0	(Intercept)	0.026	0.082		0.315	0.754
	H_1	(Intercept)	−0.130	0.152		−0.856	0.396
		Gender ratio in group	0.457	0.374	0.175	1.221	0.228
Facilitator ratio in group	H_0	(Intercept)	0.125	0.035		3.538	< .001 ***
	H_1	(Intercept)	−0.058	0.135		−0.429	0.668
		Facilitator ratio in group	1.439	1.029	0.088	1.399	0.163
Avg. Design Mindset score in group	H_0	(Intercept)	0.026	0.082		0.315	0.754
	H_1	(Intercept)	−2.211	1.662		−1.330	0.190
		Avg. Design Mindset score in group	0.500	0.371	0.193	1.348	0.184
Avg. facilitator Design Mindset in group	H_0	(Intercept)	0.091	0.046		1.971	0.050 **
	H_1	(Intercept)	−0.304	0.425		−0.715	0.475
		Avg. facilitator Design Mindset in group	0.083	0.089	0.074	0.935	0.351

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

5.4.4 Variables Influencing the Development of Design Mindset

5.4.4.1 Initial Analysis of Individual Variables

To identify the relationships of each independent variable to the learning outcomes of *Method Teaching*, we conducted separate linear regression analyses for each of the ten variables. Aligning with our model of *Method Teaching* (see Figure 5-2), we relied on the differences between the pre-and post-intervention scores of *Design Mindset* (*Design Mindset_DELTA*) as a measure for the participants' learning and, thus, as our dependent variable.

The independent variables shown in Table 5-1, along with pre-intervention scores of *Design mindset* (*T1_Design Mindset*), are used as the independent variables for these analyses. All these variables were collected in the pre-intervention questionnaire.

Table 5-3 shows the model summaries for all variables and represents the goodness of fit and the contribution of each model (H_1) and their null hypotheses (H_0). The models for *T1_Design Mindset*, $F(1,252) = 40.08$, $p < .001$, $R^2 = 0.137$, *Self-efficacy*, $F(1,252) = 6.97$, $p = 0.009$, $R^2 = 0.027$, *Ambiguity tolerance,* $F(1,252) = 14.46$, $p < .001$, $R^2 = 0.054$, indicate significant improvements in performance compared to their null models. As indicated by the *Adjusted* R^2, the three models explain 13.4%, 2.3%, and 5.1% of the variance of *Design Mindset_DELTA,* respectively.

At the other end of the spectra, *Excited about course* (*Adjusted* $R^2 = -0.004$) and *Avg. facilitator Design Mindset in group* (*Adjusted* $R^2 = -0.001$) both explain less of the variance of *Design Mindset_DELTA* than their respective H_0-models, suggesting they are not suitable for understanding the changes in *Design Mindset* scores.

The one-way ANOVAs shown in Table 5-4 support rejecting the null hypothesis for the models including *T1_Design Mindset*, $F(1,252) = 40.08$, $p < .001$, *Self-efficacy,* $F(1,252) = 6.97$, $p = 0.009$, and *Ambiguity tolerance*, $F(1,252) = 14.46$, $p < .001$. The result indicates that these three models account for significant variance, while the remaining models fail to do so.

Table 5-5 displays the coefficients of each of the variable models, and the relationships to the development of *Design Mindset* are illustrated in Figure 5-4 (green lines indicate a positive relationship, while red lines indicate a negative relationship. The line width shows the strength of the relationship based on the standardised coefficients, and the dashed lines indicate that the results were not statistically significant). The unstandardised coefficients tell us the amount *Design Mindset_DELTA* changes when the independent variable increases by one and anything else is static (e.g. if *T1_Design Mindset* increases by 1, *Design Mindset_DELTA* will decrease by −0.425). As such, Table 5-5 gives us the directionality of the relationship between the different variables and the changes in *Design Mindset*. Perhaps the negative relationship between *Design Mindset_DELTA* and *T1_Design Mindset*, *Sensation-seeking*, and *Will use tools* is most noteworthy in this context, even though the model for the latter is not considered significant. These results suggest that the hypothesised positive relationship between these three variables must be rejected.

5.4.4.2 Analysis of Multiple Variables

To investigate the individual and combined effects of the different variables on the learning outcomes of *Method Teaching*, we conducted a forward selection stepwise multiple linear regression analysis for *Design Mindset_DELTA*. We employed stepwise analyses to systematically select the most influential variables for inclusion in the final regression models.

The independent variables *T1_Design Mindset, Sensation-seeking, Self-efficacy, Ambiguity tolerance, Will use tools, Facilitator ratio in group*, and *Avg. facilitator Design Mindset in group* was included in the analysis. *Gender ratio in group* and *Avg. Design Mindset score in group* were excluded to avoid the immense loss of degrees of freedom (48 vs 253) resulting from the number of respondents the variable could be calculated for (see Section 5.4.2). Neither showed a significant relationship to *Design Mindset_DELTA* on their own (see Table 5-3, Table 5-4, and Table 5-5), and both have a relatively small sample size (see Table 5-1). Similarly, we excluded *Excited about course* and *Avg. facilitator Design Mindset in group* due to their negative Adjusted R^2 values (see Table 5-3), indicating that they do not improve the predictive model.

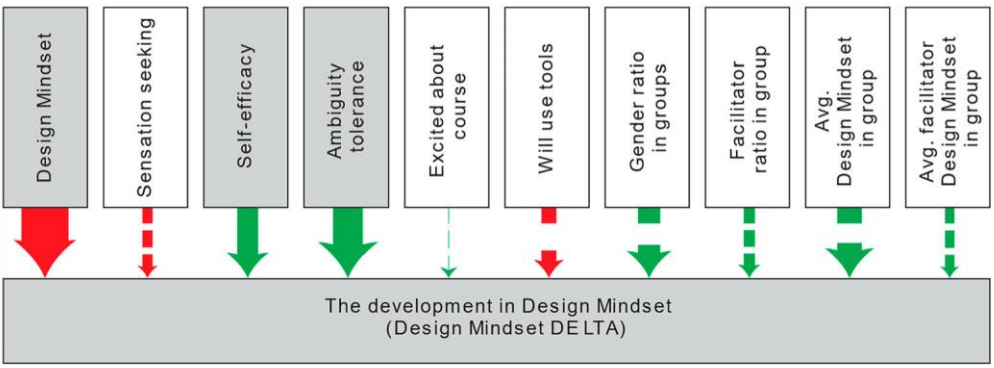

FIGURE 5-4: VISUALISATION OF THE REGRESSION MODELS OF THE INDIVIDUAL VARIABLES (COLOUR INDICATES DIRECTIONALITY, LINE WIDTH, THE STRENGTH OF THE RELATIONSHIPS BASED ON THE STANDARDISED COEFFICIENTS AND DASHED LINES NON-SIGNIFICANT RELATIONSHIPS ($P > .05$)

The significance of *F-change*, displayed in Table 5-6, indicates that the model provides meaningful information about the changes in *Design Mindset*. The model explains 27.7% of the variance of the changes in *Design Mindset*, as indicated by the *Adjusted* R^2. Additionally, the *p*-value ($p = 0.002$) suggests statistical significance in explaining the variability of *Design Mindset* scores.

The one-way ANOVA shown in Table 5-7 supports rejecting the null hypothesis. The *p*-values indicate highly significant model fits, while the *F*-values show diminishing returns in explanatory power as less predictive variables are added to the model.

As could be expected based on the initial analyses of the variables, Table 5-8 shows that *T1_Design Mindset, Self-efficacy, and Ambiguity tolerance* are included in the best model for explaining the changes in *Design Mindset* scores (*Design Mindset_DELTA*). More surprisingly, *Sensation-seeking* is also included in this model, indicating an interaction between the independent variables that increases the relevance of *Sensation-seeking*.

Similar to the initial analyses, Table 5-8 also shows a negative relationship between the changes in *Design Mindset* and the variables *T1_Design Mindset* and *Sensation-seeking*, contradicting our initial hypotheses.

The relationships are visually summarised in Figure 5-5 (green lines indicate a positive relationship, while red lines indicate a negative relationship. The line width shows the strength of the relationship based on the standardised coefficients).

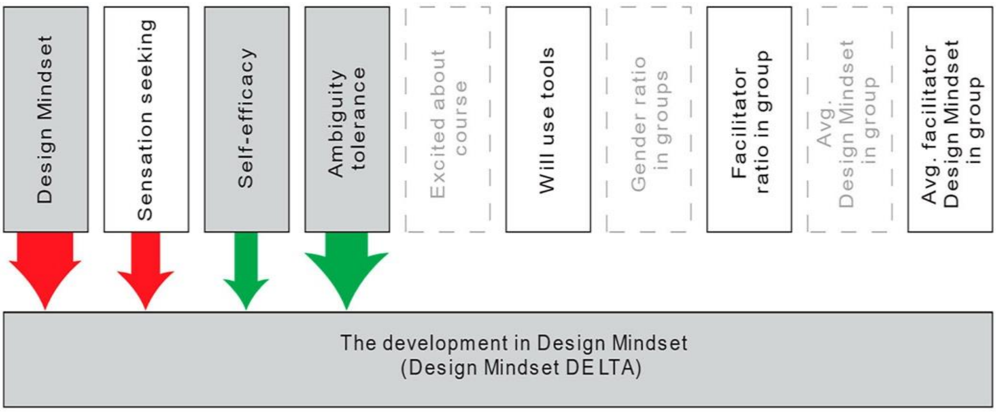

Figure 5-5: Visualisation of the regression model including multiple variables (*p*< .05; colour indicates directionality and line-width the strength of the relationships based on the standardised coefficients. The muted boxes reflect the variables not included in the regression analysis).

Table 5-6: Models summaries—Multiple variables.

	Model	*R*	*R²*	*Adjusted R²*	*RMSE*	*R² Change*	*F Change*	*df1*	*df2*	*p*
Design Mindset_DELTA	1				0.559			0	253	
	2	0.370	0.137	0.134	0.520	0.137	40.080	1	252	< .001***
	3	0.472	0.223	0.217	0.494	0.086	27.768	1	251	< .001***
	4	0.509	0.259	0.250	0.484	0.036	12.154	1	250	< .001***
	5	0.537	0.288	0.277	0.475	0.029	10.193	1	249	0.002**

* p < 0.05; ** p < 0.01; *** p < 0.001.

Table 5-7: ANOVA—Multiple variables

	Model	*df*	*F*	*p*
Design Mindset_DELTA	2	1	40.1	< .001***
		252		
		253		
	3	2	36.1	< .001***
		251		
		253		
	4	3	29.2	< .001***
		250		
		253		
	5	4	25.2	< .001***
		249		
		253		

Note. The intercept model is omitted, as no meaningful information can be shown.
* *p* < 0.05; ** *p* < 0.01; *** *p* < 0.001.

TABLE 5-8: COEFFICIENTS—MULTIPLE VARIABLES

	Model		Unstandardised	Standard Error	Standardised	*t*	*p*	Collinearity Statistics	
								Tolerance	VIF
Design Mindset_DELTA	1	(Intercept)	0.127	0.035		3.635	< .001***		
	2	(Intercept)	2.006	0.299		6.720	< .001***		
		T1_Design Mindset	-0.425	0.067	-0.370	-6.331	< .001***	1.000	1.000
	3	(Intercept)	1.096	0.332		3.300	0.001***		
		T1_Design Mindset	-0.477	0.065	-0.416	-7.387	< .001***	0.977	1.024
		Ambiguity tolerance	0.250	0.048	0.297	5.270	< .001***	0.977	1.024
	4	(Intercept)	1.231	0.327		3.761	< .001***		
		T1_Design Mindset	-0.481	0.063	-0.419	-7.610	< .001***	0.976	1.024
		Ambiguity tolerance	0.317	0.050	0.376	6.307	< .001***	0.835	1.198
		Sensation-seeking	-0.095	0.027	-0.205	-3.486	< .001***	0.854	1.172
	5	(Intercept)	0.840	0.344		2.439	0.015*		
		T1_Design Mindset	-0.506	0.063	-0.441	-8.082	< .001***	0.962	1.04
		Ambiguity tolerance	0.280	0.051	0.332	5.531	< .001***	0.792	1.262
		Sensation-seeking	-0.104	0.027	-0.226	-3.877	< .001***	0.843	1.186
		Self-efficacy	0.133	0.042	0.181	3.193	0.002**	0.886	1.129

Note. The following covariates were considered for analyses but not necessarily included in the models: T1_Design Mindset, Sensation-seeking, Self-efficacy, Ambiguity tolerance, Will use tools, Facilitator ratio in group, Avg. facilitator Design Mindset in group
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

5.5 Discussion

In this study, we have investigated how individual and contextual factors affect the development of *Design Mindset* through *Method Teaching*. The results show that *Method Teaching* generally improves *Design Mindset* as we hypothesised (see Section 5.1.2). We find that the changes in *Design Mindset* are best predicted by the individual factors—*Design Mindset, Sensation-seeking, Self-efficacy,* and *Ambiguity tolerance*—rather than the contextual factors. The results also show that several variables were negatively correlated with the development of *Design Mindset*, contrary to our hypotheses (see Section 5.1.2). Among the variables included in the final regressing model (see Section 5.4.4.2), both *Design Mindset* and *Sensation-seeking* were found to be negatively correlated with the development of *Design Mindset*.

5.5.1 Design Mindset and Method Teaching

Considering that neither *Iteration, Conversation with the situation*, nor *Co-evolution of problem-solution* of the sub-constructs of *Design Mindset* was statistically significant, the results indicate that the development of *Design Mindset* was driven mainly by the improvements in the sub-construct *Imagination*. *Imagination* is associated with divergent and hypothetical thinking (Lavrsen et al., in press). While both concepts were in play during the course, looking closer at *Method Teaching* in general and the specific case studied here, we would have expected the development of *Design Mindset* to be driven mainly by *Conversation with the situation* and *Co-evolution of problem-solution*. Despite aspects related to both being more explicitly taught and taking up more time in the course than any aspects related to *Imagination*, neither improved significantly. These results might indicate that the specific setup of *Method Teaching* employed in the studied course is skewed towards stimulating development in *Imagination* rather than the other sub-constructs of *Design Mindset*. Alternatively, the beliefs and attitudes related to *Imagination* might be more susceptible to change than the other sub-constructs of *Design Mindset*, at least within the short time frame of the case presented here.

Even though insignificant, it is also worth addressing the negative changes to *Iteration*. The negative development is worrisome since working iteratively is essential to designing and implementing learning and new insights into the design process (Crismond & Adams, 2012; Dorst, 2011; Lavrsen et al., in press). Not addressing the negative development could result in poorer performance on design tasks and less effective learning in future design situations. These findings generally indicate a need to better understand the relationship between the specific components of *Method Teaching* and the development of *Design Mindset* to improve the effectiveness of *Method Teaching*.

5.5.2 Variables Influencing the Effectiveness of Method Teaching

The results from the regression analyses show that several of the variables included in the multiple regression models had no significant influence on changes in *Design Mindset*. Both of the group factors and the factors related to motivation had insignificant predictive power. The dominant variables across the models are the initial *Design Mindset* score and the three personality traits (see Figure 5-5).

5.5.2.1 The Influence of Initial Design Mindset on Developing Design Mindset

As shown in Table 5-3, 13.4% of the variance of the change in *Design Mindset* between the start and end of the course can be explained by the participants' initial *Design Mindset.* It is, therefore, not surprising that it is significant when included with other variables in the regression models investigating the changes in *Design Mindset*. As highlighted in Figure 5-5, participants' initial *Design Mindset* correlates negatively with the overall change in *Design Mindset*. While the negative relationship suggests that *Method Teaching* is more effective for students starting with a lower *Design mindset* score, it does not necessarily mean that higher scores result in negative development. The negative relationship implies that as the initial *Design Mindset* scores increase, the improvements in *Design Mindset* become smaller. Despite contradicting our initial hypothesis (see Section 5.1.2), this is not surprising as those participants initially scoring higher might be closer to their maximum potential, making it harder to improve significantly.

Taking together with the limited reliability of *D-Mindset0.1* (ω= 0.522), some of the negative relationships might also be ascribed to the statistical phenomenon: 'regression to the mean.' Regression to the mean suggests that individuals with initially extreme scores, high or low, are more likely to move closer to the mean in subsequent measurements due to random fluctuations. This is supported by the data showing that 67% (n = 55) of the 82 participants who experienced a drop in *Design Mindset* scores scored above average in *Design Mindset* in the pre-intervention test (T1). Compared with the group of participants with negative development and scoring below average in *Design Mindset* in the initial test (n = 27), who had an average drop of −0.33, the above-average group on average dropped −0.55 in *Design Mindset* scores, a statistically significant difference (Welch's $t(78)$ =−2.901, p = 0.005, Cohen's d = 0.619). These findings suggest the need for caution in interpreting the relationship between initial *Design Mindset* scores and changes in *Design Mindset* and highlight the importance of continually improving the *Design Mindset inventory (D-Mindset0.1)* to mitigate the effects of 'regression to the mean' in future studies.

5.5.2.2 Influence of Sensation-Seeking

Despite having no statistically significant relationship to change in *Design Mindset* (*Design Mindset_DELTA*) in the initial analysis of the individual variables (see section 5.4.4.1), we find *Sensation-seeking* included in the multi-variable model, indicating that it interacts with the other variables in a way that makes it more relevant than when on its own (see section 5.4.4.2).

Considering that our prior research (Lavrsen et al., in press) has found a positive correlation between *Sensation-seeking* and *Imagination* and that the changes to *Design Mindset* in this study seem to be driven by changes to this subconstruct, the negative relationship to the development of *Design Mindset* is interesting. It indicates that while being a sensation seeker is positively correlated with the subconstruct of *Imagination* and likely helps the sensation seekers be more creative (Lavrsen et al., in press), in the context of *Method Teaching*, these attributes likely influence the learning negatively. This might be due to sensation seekers being prone to distractions, e.g. if the course is not stimulating enough, sensation seekers might be likelier to daydream (Franken & Rowland, 1990; McDaniel et al., 2001). The negative effect of *Sensation-seeking* might be enhanced by the negative development in *Design Mindset* among participants with high pre-intervention *Design Mindset* scores (discussed above) since the combination of high *Sensation-seeking* and *Design Mindset* scores could suggest an increased risk of boredom due to prior experience with design and innovation.

5.5.2.3 Influence of Self-Efficacy

The regression models show a positive relationship between the development of *Design Mindset*, *Ambiguity tolerance,* and *Self-efficacy*, aligning with our hypotheses. The positive relationship with *Self-efficacy* is likely driven by higher *Self-efficacy* providing the necessary confidence to persist in the complex context associated with designing, which is a mainstay of *Method Teaching*. In our previous research, we have suggested a similar argument for the more general relationship between *Self-efficacy* and *Design Mindset* (Lavrsen et al., in press).

5.5.2.4 Influence of Ambiguity Tolerance

Ambiguity tolerance seems to facilitate reflection in and on action, which requires an acceptance of processes and methods being more like guidelines than strict procedures that must be followed. Accepting this ambiguity as part of the design process likely prompts the students to reflect on their method usage and design practices, stimulating learning. Similarly, *Ambiguity tolerance* has been related to the unfreezing of mental models (Herman et al., 2010), suggesting that *Ambiguity tolerance* generally facilitates learning and changes in mindset.

5.5.3 Limitations and Future Research

While our study design allows us to collect data in a real-world context, it also means we had limited control over the factors influencing the learning environment and the learning. While we have shown that several variables influence the effect of *Method Teaching*, the limited control over the intervention leaves much in terms of determining what aspects of *Method Teaching* are affected by what variables and how *Method Teaching* itself influences the development of *Design Mindset*. Without complete control, a direct measurement of the intervention variable, and a control group, it is difficult to establish a direct causal link between the intervention and the change in *Design Mindset*. Various factors, including the intervention, other unmeasured variables, and time-related effects, may have influenced the relationship between pre- and post-intervention measures. Considering, for example, the short timeframe of the study—twelve workdays—it is impressive that we see significant improvement in Design Mindset. However, this improvement would likely be more pronounced given more time. Similarly, the influence of the different variables analysed might change if the development of *Design Mindset* were measured over a more extended period, such as a semester-length course or even over a whole education. It is not unlikely that time could moderate the effect of several variables, making their influence more pronounced and perhaps even changing the directionality of the influence to match our hypothesis better.

The patterns observed in the relationships between *Sensation-seeking, Self-efficacy, Ambiguity tolerance*, and the changes to *Design Mindset* underscore the complexity of variables influencing mindset development in the context of *Method Teaching*. Future research could delve deeper into these dynamics to investigate the interplay between personality traits, *Method Teaching*, and mindset development, ultimately informing more effective educational interventions and strategies in design education.

Lastly, the quality of the results and their interpretation depends on the quality of the instruments used to measure them. As the measure of the students' learning and the core measure throughout this study, the quality of *D-Mindset0.1* has a great potential to influence the study results, as already indicated in Section 5.5.2.1. *D-Mindset0.1* was developed for this study and is, thus, still in its infancy. There are still a lot of unanswered questions regarding its reliability and validity (Lavrsen et al., 2023, in press). While the developmental stage of *D-Mindset0.1* influences the result of this study, it also helps further our understanding of the construct and can, thus, inform the development of the *Design Mindset Inventory*.

5.6 Conclusion

This study has outlined the concept of *Method Teaching* and provided valuable insights into its effectiveness in enhancing *Design Mindset*. The findings reveal that while *Method Teaching* leads to improvements in *Design Mindset*, the specific variables influencing its effectiveness are complex and multifaceted. The analysis suggests that while *Self-efficacy* and *Ambiguity tolerance* positively influence *Design Mindset* development, *Sensation-seeking* may have a more complex relationship, potentially distracting students from focused learning. Overall, this study contributes to our understanding of *Method Teaching* and its impact on fostering *Design Mindset* while also highlighting avenues for continued investigation and improvement in design education.

6 Article III: Balancing Cognitive Load in Design Work

Balancing Cognitive Load in Design Work: A Conceptual and Narrative Review

Jakob Clemen Lavrsen, Jaap Daalhuizen

Abstract:
Designers address complex and even wicked problems, which requires them to deal with high levels of uncertainty and ambiguity, requiring high levels of mental effort. The cognitive load of designing is thus likely to affect design behaviours, activities and method use. However, the nature of design work presents a challenge in applying existing theory on cognitive load to explain and predict design behaviour. Especially designers' tendency to expand the design space to increase creative potential seems to fall outside the current theories on cognitive load. Following recent calls for theory-building within design, this paper outlines a conceptual framework mapping the relationship between cognitive load and the process of framing and reframing. We examine this dynamic between cognitive load and design by drawing upon theories rooted in cognitive science and information processing. Through a narrative review and conceptual modelling, we propose a model suggesting that cognitive load can be managed.

Keywords: Design cognition; Cognitive load; Design methods; Conceptual mapping

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6.1 Introduction

Design is a multifaceted cognitive process that unfolds as a complex interplay of creativity, problem-solving, and decision-making (Cross, 2001; Finke et al., 1992; Hay et al., 2017). Despite designers and their cognitive processes being central to the design process (Cash et al., 2019; Daalhuizen, 2014), much design research has ignored designers' role in the design process (Dorst, 2008). Viewing designing through the lens of cognitive load, we can draw on existing theories on the role of cognitive load on information processing and performance to expand our understanding of how designers interact with their surroundings to deliver quality designs.

While still an underexplored research area, previous research has found connections between cognitive load and both creativity (Redifer et al., 2019) and design (Calpin & Menold, 2023; Sun et al., 2014; Zimmerer & Matthiesen, 2021). Furthermore, there are discrepancies between the results, indicating the need for further exploration of these relationships.

Zimmerer & Matthiesen (2021) find a weak negative correlation between cognitive load and performance on analytical design tasks like functional analysis. Similarly, Redifer et al. (2019) find that lower cognitive load is positively correlated with performance on divergent thinking tasks. These findings align with what the current theories on cognitive load would predict, mainly that reduced cognitive load increases performance (Hancock et al., 2021; Sweller et al., 2019).

Conversely, Sun et al. (2014) show that experienced designers expend more cognitive effort, perceiving a higher cognitive load yet delivering a higher quality output than novice designers. Calpin & Menold (2023) support these findings, finding a correlation between higher cognitive load and effort with 'uniqueness of ideas' and 'usefulness of idea' and 'elegance of ideas', respectively. While inconclusive, these findings suggest that performance on some design tasks can be increased by actively increasing cognitive load. Sun et al. (2014) ascribe their result to the fact that the more experienced designers understand the problem on a deeper level, comprehending the complexity of the design task more fully. Taken to the extreme, designers have been observed to approach even well-defined problems as if they were wicked (Cross, 2001).

This paper will make the case that the contradictory results can be explained by design tasks differing from other complex cognitive tasks due to the wicked nature of design problems. Wicked problems have no one correct or optimal solution, they are not stable, and their scope and framing are influenced by how problem solvers understand the problem space and the world more generally (Rittel & Webber, 1973), meaning the cognitive load associated with solving a wicked problem changes depending on framing. This malleability of design problems falls outside the current theories on cognitive load developed to describe tasks with clearly defined end-states and success criteria. Therefore, there is a need to explore the implications of this difference when employing theories on cognitive load within the design field.

Through conceptual modelling (see Jaakkola, 2020; Wacker, 1998), we begin to identify connections between cognitive load and the core design activities of framing and reframing. As such, this paper aims to provide an initial conceptualisation of the role of cognitive load in relation to these core design activities. Linking design activities to existing theories related to cognitive load extends the theoretical foundation for understanding design cognition. In doing so, we also expand the existing theories on cognitive load to explain the discrepancies between current results on cognitive load within design. Furthermore, a conceptual model has the potential to guide systematic exploration of the interaction between designers and the design context more generally, including the effectiveness of new and existing design methods, techniques and processes to facilitate design activities.

This paper follows the recent calls for theory-building in design research (Cash, 2018) and ventures into psychology and cognitive science to explain design phenomena (see Cash et al., 2019). Generally, understanding the cognitive processes of designing holds the promise of advancing design research (Cash, 2018) and improving design practice by developing better design methods and strategies (Jin & Benami, 2010).

6.2 Method

Within a theory-building approach, this paper falls under analytical conceptual research and, more precisely, conceptual modelling, which involves deducing relationships from theories and expressing new conceptual perspectives (Wacker, 1998).

We use a narrative literature review to support the framing of design in terms of balancing cognitive load. Presenting literature in a condensed format and discussing theory in context, narrative reviews are ideal for presenting conceptual matters (B. N. Green et al., 2006). Narrative reviews are more exploratory than systematic reviews (Demiris et al., 2019). They follow no specific protocol and, thus, provide more flexibility to integrate sources and explore emerging themes (Demiris et al., 2019). Therefore, no systematic literature search was conducted. Rather, the literature was included organically as themes emerged and based on its relevance and ability to drive the narrative forward. It was sourced both by keyword searches in different databases and by exploring references of the papers included in this paper. The literature spans several theories related to design or cognition, chosen to shed light on the relationship between cognitive load and the design activity of framing and reframing. However, it is not a comprehensive review of the potentially relevant literature but rather a preliminary exploration of the phenomenon.

While drawing on different theories points towards theoretical integration and synthesis, this is outside the scope of this paper due to the shallow nature of narrative reviews.

6.3 Cognitive Capacity

The human capacity to process information is not limitless. It is informed by the cognitive capacity of working memory. Cognitive capacity '... refers to a limited-supply cognitive resource that can be allocated flexibly depending on the demand of the task at hand' (Hambrick & Engle, 2003, p. 181). Working memory is not strictly speaking about memory but about managing attention (Stanovich, 2009). The primary function of working memory is to keep relevant information and representations activated and in focus (Hambrick & Engle, 2003; Stanovich, 2009). As such, it serves as an intermediary between long-term memory and the external world (M. S. Sanders & McCormick, 1993; Sweller, 2009).

Miller's (1956) seminal research suggested that the average person can manage approximately seven pieces of information in their working memory at any given time. This capacity can be extended by structuring information into larger, meaningful chunks (Miller, 1956). Expert chess players can, for example, remember the placement of more pieces on a chessboard if their arrangement resembles configurations realistic to gameplay than if not (Sweller, 1988). This ability depends on information stored in long-term memory and the quality of schemas and mental models of the world, connecting knowledge and expertise to performance on cognitive tasks (Chandler, 1993; Sweller, 2023).

When retrieving information from long-term memory, working memory is less restricted by cognitive capacity (Sweller, 2009, 2023). However, retrieval itself is not perfect (M. S. Sanders & McCormick, 1993); it depends on appropriate search processes (Gilhooly et al., 2014) and the organisation of the information both in working and long-term memory (M. S. Sanders & McCormick, 1993).

As we shall see in the following, human information processing and its limitations inform the theories on cognitive load and, thus, lay the foundation for understanding the role of cognitive load in the design process.

6.4 Managing Cognitive Load

The limited cognitive capacity of our brain influences our ability to process information, solve problems, and make decisions. Cognitive tasks that exceed the cognitive capacity, such as dealing with complex or overwhelming information, can result in cognitive overload and harm performance (Paas & Van Merriënboer, 1994; Sweller, 1988, 2023).

There are two main ways to reduce cognitive load: reducing taskload or reducing ineffective load. Taskload is the objective load of a task (Charles & Nixon, 2019; Hancock et al., 2021) and can be reduced by making the task less complex (Sweller et al., 2019). Here, Cognitive Load Theory focuses on reducing extraneous load (Sweller et al., 2019). Extraneous load is related to how the task is presented and structured and, specifically, the aspects not relevant to solving the core task (Sweller et al., 2019). Reducing extraneous load is effectively to remove the noise surrounding the task. The advantage of reducing extraneous load is that the core task remains the same. However, depending on the expertise of the problem solver, it might still be necessary to simplify the task to bring it within the scope of their cognitive capacity.

The other way to reduce cognitive load is to reduce ineffective load. Ineffective load is part of the experienced cognitive load and arises from inefficiencies of the individual problem-solving strategies and differences in knowledge and experience (Xie & Salvendy, 2000). The primary way to reduce ineffective load is by training (Chandler, 1993; Paas & Van Merriënboer, 1994; Sweller et al., 2019). As we have seen, domain knowledge reduces the strain on working memory by providing highly structured mental representations of a problem space. Another important function of training is the automation of processing (Paas & Van Merriënboer, 1994). Automating happens when procedures through training and repeated practice become second nature, no longer requiring conscious processing (Chandler, 1993). Automation shifts processing from Type 2 processing, which heavily taxes working memory, to Type 1, the brain's default mode (Stanovich, 2009). Type 1 processing is rapid, intuitive, and subconscious, reducing working memory load (Evans et al., 2005; Stanovich, 2009). Type 2 processing involves deliberate, analytical, and reflective thinking, demanding greater working memory resources (Evans et al., 2005; Stanovich, 2009). As such, automating processes frees up cognitive resources and reduces the cognitive load associated with a task (Chandler, 1993; Kalyuga, 2009; Paas & Van Merriënboer, 1994; Stanovich, 2009).

Sweller (2023) also indicates that instructions, to some extent, can stand in for lacking task-specific expertise, meaning that a task can be performed more efficiently even without training. Task-specific expertise refers to the level of ability to perform effectively or even automatically on a class of tasks and pertains to knowledge structures and procedures for dealing with this class of tasks (Kalyuga, 2009).

Whether reducing cognitive load is an effective strategy for increased performance depends on the level of cognitive load the task solver experiences. The Yerkes-Dodson Law suggests that both too much and too little cognitive load impair performance (Yerkes & Dodson, 1908; Zimmerer & Matthiesen, 2021). Flow

Theory makes a similar claim in that 'flow' happens when the challenges of a task match the skill level of the individual engaging in the task (Csikszentmihalyi, 2013). Both theories report that people tend to disengage from a task if it is too challenging or not challenging enough. The Yerkes-Dodson Law, often illustrated by an inverted U, tells us that as stimuli increase, so does performance until a certain point, after which performance begins to drop (Yerkes & Dodson, 1908; Zimmerer & Matthiesen, 2021). Regarding cognitive load, this point is likely related to cognitive capacity but also informed by motivation—meaning that as long as the task solver is both motivated and has free cognitive capacity, performance can be increased by increasing cognitive load.

Figure 6-1 provides an initial model for understanding the relationship between the different aspects of cognitive load. In addition to the aspects mentioned above, the model includes effective workload and management load.

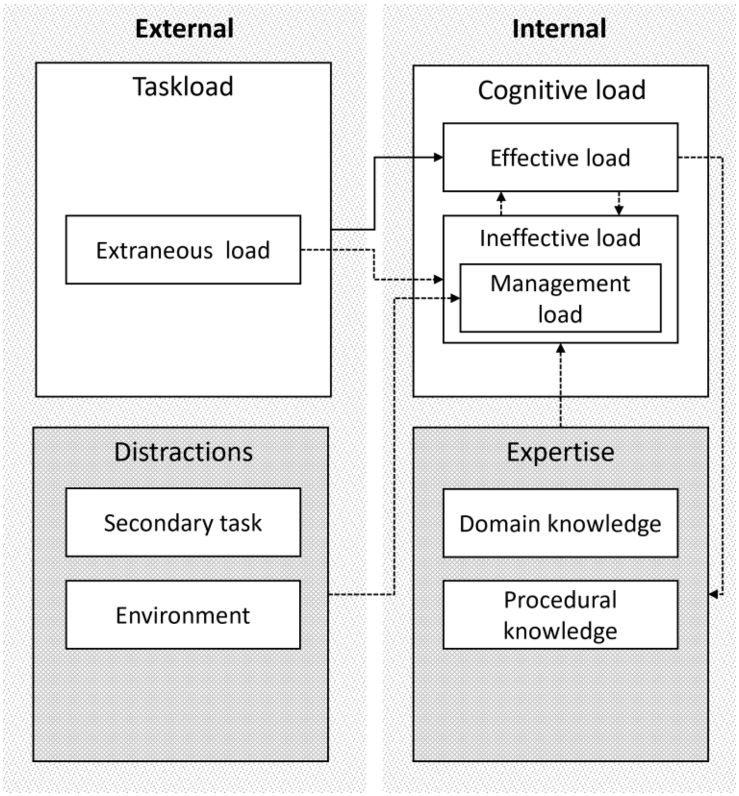

FIGURE 6-1: MODEL OF COGNITIVE LOAD SHOWING THE RELATIONSHIP BETWEEN TASKLOAD (+EXTRANEOUS LOAD), COGNITIVE LOAD (+EFFECTIVE LOAD, INEFFECTIVE LOAD (+MANAGEMENT LOAD)), DISTRACTIONS (+SECONDARY TASK, ENVIRONMENT) AND EXPERTISE (+DOMAIN KNOWLEDGE, PROCEDURAL KNOWLEDGE).

Xie & Salvendy (2000) define effective load as the minimum cognitive effort required to solve a task under optimal conditions and efficiency and is directly related to the taskload. The combined effective and ineffective workload is what is called intrinsic cognitive load in Cognitive Load Theory (Sweller et al., 2019). Going forward, we will refer to this combined cognitive load as 'cognitive load.'

Management load is related to managing, prioritising, and shifting between multiple tasks (Xie & Salvendy, 2000). Managing multiple simultaneous tasks results in a higher overall cognitive load than doing the same task one after the other (Hancock et al., 2021). It is related to the core function of working memory: focusing attention.

The model highlights that taskload is directly related to effective load. Extraneous load is part of the taskload, thus, influences effective load. It is also connected to the ineffective load to indicate that extraneous load, by its very nature, introduces inefficiencies into the problem-solving process. Management load is shown to be part of the ineffective load and conceptualised as the part of the ineffective load prompted by external factors unrelated to the primary task or shifting between tasks, broadly referred to as distractions. Lastly, the model indicates the relationship between ineffective load and expertise. The arrows from effective load to expertise and from expertise to ineffective load point towards the interaction between the task and the problem solver, resulting in the specific handling of the task.

6.5 Cognitive Load and Design Problems

Whenever possible, the brain defaults to the least cognitive taxing process possible and only fully engages if all else fails (Stanovich, 2009). However, it is in the designer's interest to maximise the creative potential of a problem and consider as much of the design space as possible (Christensen & Ball, 2018). This is indicated by designers' tendency to approach well-defined problems as if they were wicked (Cross, 2001) and Sun et al.'s (2014) findings showing that experienced designers expend more cognitive effort than novices on the same task. Sun et al. (2014) also found that the experienced designers were more ‘cognitive efficient’ than the less experienced designers, meaning they spent relatively little cognitive effort to achieve the quality of their proposed solutions. They suggest that the additional effort expended by the experienced designers is the result of them identifying more relevant aspects of the design space. This is related to the problem and how it is framed.

6.5.1 Exploring the Design Space

A problem frame defines the nature of a design problem and points towards how the problem can be resolved (Dorst, 2011; Rittel & Webber, 1973). Dorst (2011) identified two levels of problem frames: one requiring abduction-1 problem-solving and one requiring abduction-2 problem-solving. The first level relates to problems where both the nature of the design space and the wanted outcome have been defined (Dorst, 2011). Solving a problem following an abduction-1 approach indicates an acceptance of the problem frame and might be an expression of what can be called a 'business-as-usual' approach and a biased understanding of the problem space. Framing a problem space the same way, again and again, is less cognitively taxing and allows for the aggregation of high levels of domain knowledge. However, it also runs the risk of oversimplifying the design space, overlooking, excluding or ignoring essential components. As the saying goes: ‘If the only tool you have is a hammer, it is tempting to treat everything as if it were a nail’ (Maslow, 1966, p. x).

To avoid the preconceived framing of a problem, designers will challenge assumptions and, as a result, transform abduction-1 problems into abduction-2 problems. In abduction-2 problems, only the wanted outcome is defined, allowing designers to experiment with different framings and explore a broader range of solutions (Dorst, 2011). Following the tools metaphor, abduction-2 problems do not define the tool to be used and, therefore, let the designers figure out if the nail really is a nail or perhaps a screw. Furthermore, the broader exploration of the design space allows designers to develop a deeper understanding of the problem, potentially leading to a more fundamental reframing of it. It could, for example, be that the problem really is not about driving the nail or screw into a wall but about hanging something on the wall, opening up a whole new class of solutions. Opening the design space up essentially allows designers to reintroduce creative potential into the design space.

The 'closed' framing of abduction-1 problems can be seen as an over-constraint problem (see Onarheim & Biskjaer, 2017). The more constrained a design problem is, the less wiggle room and creative potential remain (Christensen & Ball, 2018).

Consequently, solving abduction-2 problems is more cognitively taxing. Rather than working within a narrow design space, abduction-2 problems require the co-evolution of problem and solution (Dorst, 2011, 2015) and, as such, the retention of parallel lines of thought (Lawson & Dorst, 2009). Furthermore, the more of a design space included in the framing, the more complex the problem space becomes, adding additional cognitive load to the design process. However, while increasing the cognitive load, this ‘...breadth-first approach minimises commitment and optimises design time and effort’ (Cross, 2001, p. 94).

Through the explorations of the design space and playing around with ideas, potential frames, and solutions, designers eventually find an appropriate framing (Dorst, 2015), transforming the problem back into an abduction-1 problem, to which a solution can be defined and optimised (Dorst, 2011). In other words, solving problems like a designer has as much to do with reframing problems as it has with generating solutions (Dorst, 2015).

6.5.2 Potential Load

Designers' tendency to open up the design space presents a challenge for the theories on cognitive load presented above. Research into cognitive load generally assumes that the taskload is stable. Having taskload as constant allows them to ascribe any differences in performance between individuals to ineffective problem-solving strategies. From this, it also follows that a lower cognitive load on a task must be the result of improved effectiveness and, therefore, also leads to increased performance. We see this supported by Redifer et al. (2019) and Zimmerer & Matthiesen (2021), who both find increased performance due to less cognitive load.

However, as seen above, design problems are malleable by their very nature. Design problems are often categorised as wicked problems. Wicked problems defy definition, are interconnected, essentially unique, and have no stopping rules since they have multiple solutions, none of which is definitively correct (Rittel & Webber, 1973). Having multiple potential and appropriate solutions, the same problem can be framed in many ways, all imposing different levels of taskload. When designers reframe a problem, they go beyond the initial constraints and effectively add cognitive load to the taskload, not strictly speaking necessary to solve the task. The intentional broadening of the design space is essential for the designer to ensure the best possible solution that is within their capacity to generate. Consequently, due to this intentional broadening of the design space, design expertise seems to prompt higher cognitive load despite reducing ineffective load (see Sun et al., 2014).

Because this added cognitive load leads to better performance, it can neither be classified as extraneous load because removing it would result in a poorer design outcome nor does it fit neatly into the category of ineffective load since the added cognitive load is not the result of ineffective strategies or lack of training. Consequently, while informed by the problem solver's understanding of the design space, the added cognitive load is inherently part of the taskload and thus directly related to effective load. We have called this cognitive load associated with challenging and expanding a problem space 'Potential load' (see Figure 6-2). It is the cognitive load actively added to the taskload by reframing to expand the design space and enhance the creative potential and quality of an output on a design task.

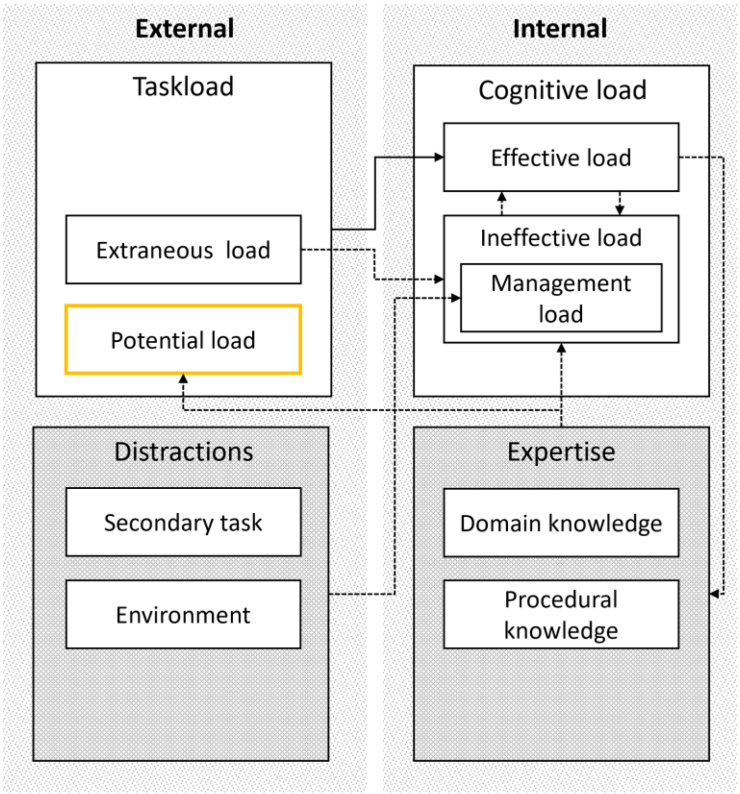

Figure 6-2: Model of cognitive load including potential load, showing the relationship between Taskload (+Extraneous load, Potential load), Cognitive Load (+Effective load, Ineffective load (+Management load)), Distractions (+Secondary task, Environment) and Expertise (+Domain knowledge, Procedural knowledge).

The addition of potential load to the model of cognitive load (see Figure 6-2) also means that taskload cannot be seen as a constant when researching cognitive load in relation to design problems. Some measure of the differences in the framing of design space is needed to compare results across individuals.

6.6 Cognitive Load and Design Problems

A central source of cognitive load is the complexity of a problem (Sweller et al., 2019). As such, the initial framing of a problem significantly influences the cognitive load imposed by a design task and how a designer will ultimately approach the problem. As we have seen, an essential part of an effective design process is the exploration and expansion of the design space. However, exploring the design space requires available cognitive resources.

As problems become more complex, they take up more cognitive capacity, eventually exceeding its limits (see Figure 6-3). On relatively simple tasks—compared to the ability and expertise of the designer—increasing the taskload constitutes little challenge. An inclination to add to the taskload in such situations likely comes down to engagement and motivation. However, as flow theory and the Yerkes-Dodson law tell us, even when not especially motivated, an individual might enrich the taskload just to make the task more enjoyable. Combined with the benefits of expanding the design space, this gives us a way to explain designers' tendency to approach well-defined problems as if they were wicked. Simply put, they have both the incentive and the cognitive capacity to increase the design space and, thus, the complexity and cognitive load required to solve the design problem.

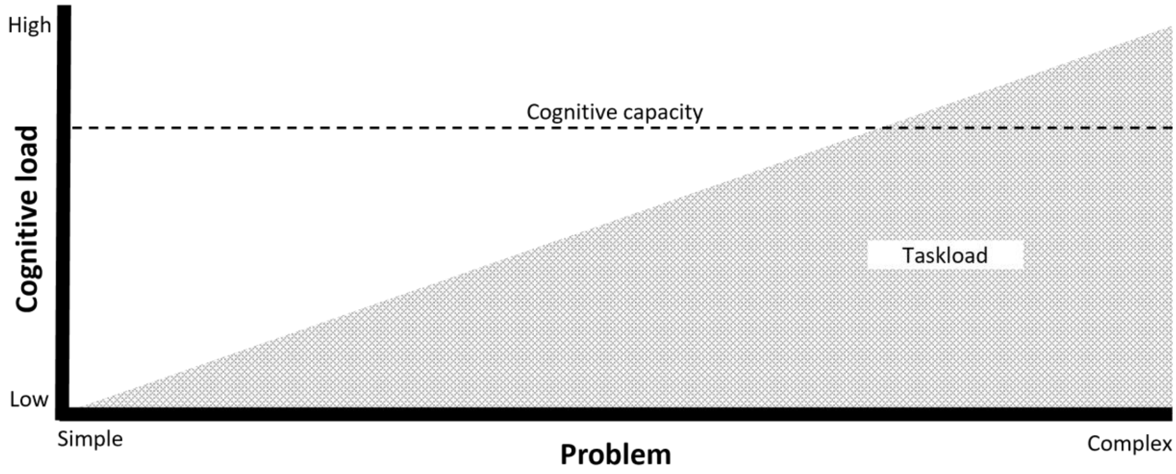

Figure 6-3: Problem and Cognitive Load, showing that Cognitive Load increases as a problem becomes more complex and eventually exceeds cognitive capacity.

As the complexity of the core task increases, exploring the design space becomes more challenging. As we near the limits of cognitive capacity, increasing the potential load might result in cognitive overload, hampering performance on the design task (Sweller, 1988, 2023). Cognitive overload reduces information retention, slows processing, and increases errors. To balance the benefits of expanding the design space and avoid cognitive overload, designers need to balance divergent and convergent design activities, as famously illustrated in the double-diamond representation of the design process (Design Council, 2003).

One essential process of balancing cognitive load is the process of framing and reframing. As suggested earlier, abduction-1 problems are less cognitively taxing. Reframing an abduction-2 problem as an abduction-1 problem, thus, reduces the taskload, helping to reduce cognitive load. By defining the 'how' of achieving the desired value, the immediate design space is decreased, freeing up cognitive capacity to explore the design space further and potentially inspire new framings. This can be done repeatedly, experimenting with different framings and solutions to achieve the desired value. Essentially, exploring different framings one at a time breaks down the problem into smaller manageable pieces and isolates aspects of the problem space—reducing cognitive load further (Sweller, 2023). Counter-intuitively, narrowing the design space can, thus, lead to further exploration and expansion of the design space and reopening of the problem space by reframing the problem as an abduction-2 problem. Through the lens of cognitive load, the core design activity of framing and reframing can, thus, be seen as a strategy for balancing cognitive load. Cash et al. (2023) present a similar idea, but rather than being driven by cognitive capacity, they suggest that the framing and reframing process is driven by balancing perceived uncertainty.

Ultimately, managing problem complexity is a trade-off between enhancing the creative potential and keeping the problem manageable. While reducing problem complexity will likely always be necessary when working on wicked problems, the theories on cognitive load tell us that there are other ways to free up cognitive resources, e.g. by training and well-designed instructions. The following section outlines the role of design methods in doing so.

6.7 Design Methods and Strategies

Design methods are '… formalised representation of a design activity that functions as a mental tool to support designer to (learn how to) achieve a certain goal, in relation to certain circumstances and resources available' (Daalhuizen et al., 2019, p. 37). Investigating design methods through the lens of cognitive load allows for a more nuanced understanding of how these methods impact the design process. By recognising the interaction between cognitive load, expertise, and method, design methods can be improved to improve design performance, as we see suggested by Cognitive Load Theory and the work related to instructional design (see Sweller et al., 2019). It adds valuable dimensions to design methodology, emphasising not just problem-solving and quality of output but also cognitive load management, contributing to potentially more efficient and creative design processes.

Design methodology generally helps to break the design process down into smaller pieces. It helps break down a complex design process into more actionable steps, which can be split further into activities and actions (see Cash & Kreye, 2017). Individual methods with specific procedures and goals help designers focus on specific aspects of both the design process and the design space (Mansoori et al., 2023)—all in line with strategies for minimising cognitive load (Sweller et al., 2019). Furthermore, many design methods and strategies include some level of externalisation of knowledge in the form of an information artefact, be it diagrams, flowcharts, sketches, sticky notes, or prototypes (Daalhuizen & Cash, 2021). Such cognitive off-loading helps further reduce the cognitive load of solving design problems (Bilda & Gero, 2007; Boldt & Gilbert, 2019). In helping to reduce cognitive load, design methods have the potential to facilitate the addition of more potential load and optimise performance.

Sweller (2023) emphasises that instructions can substitute procedural knowledge where this is lacking. Procedural knowledge refers to the knowledge about the processes, techniques, and methods involved in performing specific tasks. It is related to the task-specific expertise mentioned earlier and is the knowledge laying the foundation for the automation processes. While training helps reduce cognitive load, providing tools and strategies to solve problems efficiently and frame them appropriately might make it possible for people with limited training to handle situations they otherwise could not. As expertise and procedural knowledge grow, the formalised design methods ideally become replaced by internalised strategies in a more heuristic form (Daalhuizen & Hjartarson, 2022; Lavrsen et al., 2022), reducing the cognitive load associated with employing the strategies (Chandler, 1993; Paas & Van Merriënboer, 1994; Sweller et al., 2019). As such, design methods play a central role in developing design expertise and reducing ineffective load.

For methods to be effective, they must result in a net reduction of cognitive load compared to what it would otherwise require to achieve similar results (Sweller et al., 2019). Here, the manifestation of the method and the method content become central (see Daalhuizen & Cash, 2021). Using a method should be seen as a secondary task in relation to the primary task of solving the design problem and can, as such, be seen as a distraction (see Figure 6-2). Any extraneous load imposed by poor method design not only takes up resources for the primary task but also runs the risk of making the method unviable as a tool for reducing cognitive load.

The relatively low method uptake in the industry (Lavrsen et al., 2022; Wallace, 2011) and why new methods are often sought out in response to new or challenging problems (Gericke et al., 2016; Schønheyder & Nordby, 2018) could potentially be related to methods failing to achieve a net reduction of cognitive load. Finding and staging a method is time-consuming and likely cognitive taxing (see Lavrsen et al., 2022). For sourcing a method to be a viable option when up against a specifically challenging problem, the cognitive load of solving the problem adequately without a method needs to be significantly higher than the cognitive effort required to obtain, implement and solve the problem with a method.

Consequently, the lens of cognitive load also offers an additional criterion for assessing the quality of design methods. Design methods should improve cognitive efficiency, meaning that the relative effort spent in relation to the quality of the solution should be lower when using a method than not. Failing to do so, the method fails to generate a net reduction of cognitive load.

The design of methods also plays a significant role in securing a method fit (see Daalhuizen & Cash, 2021; Mansoori et al., 2023). If a method does not provide sufficient information, it can result in a misfit between the method and both the method user and the context of use, leading to ineffective method usage (Mansoori et al., 2023). What is considered sufficient information is dependent on expertise. If an individual has a large amount of relevant domain and procedural knowledge, we would expect a lower cognitive load associated with method usage since staging the method appropriately in the context should be more straightforward. Here, domain knowledge is defined in relation to the context in which the problem is situated (the design space) rather than the domain of the design profession. If either domain or procedural knowledge is insufficient to compensate for the lack of information the method provides, a misfit error is likely to occur (Mansoori et al., 2023), resulting in poorer outcomes if not compensated by additional cognitive effort.

Interestingly, poor method fit, due to procedural knowledge without domain knowledge or to avoid the additional cognitive load of finding and learning to use another method, could potentially mean a lower cognitive load on a specific task while increasing it on the overall design task. In other words, using a familiar yet not appropriate method might limit cognitive load in the moment but require additional cognitive resources down the line to compensate for insufficiencies of the method output. Similarly, choosing to use a more heuristic method over a more systematic and cognitively demanding method could reduce cognitive load at the moment but increase it at other points in the process. The point is that short-term gains do not necessarily improve performance.

Ultimately, poor method design results in increased ineffective load. Cognitive Load Theory, with its roots in instructional design, can provide rich insights into how to reduce the extraneous load imposed by design methods and help improve method performance.

6.8 Conclusion

In line with good theory-building (Wacker, 1998), this paper outlines a conceptual model, defining and describing core concepts and relationships between cognitive load and design, shedding light on the ways designers balance cognitive resources in the design process.

Starting from the observation that designers tend to approach well-defined problems as if wicked and the findings of Sun et al. (2014), we explored the potential of the theories on cognitive load to illuminate the core design activities of framing and reframing. Through an understanding of cognitive load and its management, this work challenges the conventional wisdom of minimising cognitive load to enhance performance. Instead, it emphasises that designers intentionally add complexity to problems in certain situations to boost creativity, leading us to introduce *potential load* into our framework (see Figure 6-2). Moreover, we have outlined how design methods help manage—and especially reduce—cognitive load, freeing up cognitive capacity to enhance creative potential.

In identifying *potential load*, we provide a possible explanation for the discrepancies between the research related to cognitive load within design. The continued framing and reframing of the design space, changing the complexity and taskload of the task, obscure traditional performance measures. Two individuals acting in response to the same design brief might very well be solving two very different problems in terms of scope and complexity. Only relying on measures of cognitive load might obscure the effectiveness of design methods, strategies or expertise, as we have shown that adding cognitive load can be a strategy for developing higher-quality solutions. Therefore, when studying the cognitive load of designers, it is necessary to capture a level of potential load, e.g., by obtaining a measure of the complexity of the design space informing each solution, or at least measuring their cognitive efficiency, to compare relative performance.

As we venture forward, it is clear that balancing cognitive load in design is a multifaceted endeavour, rich with possibilities and challenges, of which we have only scratched the surface. As measurable constructs, cognitive load and cognitive efficiency open up for research into how designers are influenced by, e.g., design contexts, problems, and methods. Following the framework, research into how design methods influence cognitive efficiency could, for example, pave the way for the evaluation and potential validation of the efficiency of design methods.

Understanding the cognitive processes of designing is not only a step towards advancing design research but also holds the potential to enhance design practice. Viewing design practice through the lens of cognitive load also offers an opportunity to extend awareness and take metacognitive control of the process of balancing cognitive load. A heightened awareness of cognitive limitations and strategies for managing cognitive load can potentially equip designers with the tools to be more purposeful in applying design methods and techniques, empowering them to deploy tactics and strategies more effectively and strategically. Such insight could lead to improvements in design education and open another avenue for future research.

While this paper does not offer an in-depth theoretical integration, it has laid the foundation for future research to explore these concepts. Future research should include a more systematic and thorough literature review to continue the analytical theory-building and solidify the current observations and conclusions. Likewise, further research is necessary to develop, empirically test, and validate the conceptual model's internal consistency (see Wacker, 1998).

7 Article IV: Cognitive Efficiency Using Heuristic vs Systematic Design Methods

Cognitive Efficiency Using Heuristic vs Systematic Design Methods: Assessing Theoretical Foundations and Measures of Design Performance through a Pilot Study

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Abstract:
Design methods are increasingly called upon to help address society's most complex challenges. To not overstrain individual cognitive capacity in such cases, design methods should support the cognitive efficiency of the method user. As our understanding of how method usage influences designers' cognitive load is limited, a pilot study was conducted to test the theoretical framing of method usage and the influence on cognitive efficiency of using more systematic versus heuristic methods on a concept development task. We calculated cognitive efficiency across four measures of performance. 44 master students were split between three conditions, and the differences were analysed using ANCOVAs. The free choice of approach (Condition 3) outperformed the systematic and heuristic methods. While the small sample size means that only tentative conclusions can be drawn, the results provide central insights for understanding method usage through the lens of cognitive efficiency and the study of it in design research.

Keywords: Design methods, Cognitive Efficiency, Concept development, Heuristics, Systematic design

DOI: (submitted)

7.1 Introduction

Over the last decades, designers and design methodologies have increasingly been called on to solve still more complex problems (R. Buchanan, 2001; Van Der Bijl-Brouwer & Dorst, 2017). As the reliance on design methods becomes more pronounced and the outcome of design processes more consequential, the need for quality methods has never been higher (Cash, Daalhuizen, et al., 2023). However, our understanding of how design methods deliver results is still limited (Daalhuizen & Cash, 2021).

While much design research and assessment of method performance has focused on the quality of design output, the interaction between designer and methods is potentially more significant (Cash, Daalhuizen, et al., 2023; Daalhuizen et al., 2014; Dorst, 2008). Defining design methods as mental tools (Daalhuizen et al., 2019), it becomes apparent that they should help designers improve their cognitive performance on design tasks. Designers interpret methods (Daalhuizen et al., 2014; Daalhuizen & Cash, 2021), evaluate their affordance in specific contexts (Newstetter, 1998), and implement them. Thus, designers' interactions with methods are a key variable for performance (Daalhuizen, 2014).

Putting the designer in focus, this pilot study tests an experiment to investigate how *cognitive efficiency* is influenced by using more systematic or heuristic methods to support initial concept development. Cognitive efficiency is based on the relationship between mental effort and task performance (Paas & Van Merriënboer, 1993). In piloting the experiment, we investigate four different measures of performance: three self-assessed measures related to the perceived novelty, usefulness and satisfaction with the solution and one rater-assessed related to how well the design problem has been solved. As a measure, cognitive efficiency allows us to investigate the effectiveness of design methods in terms of both the output-based performance and the cognitive load induced by its use. By reducing cognitive load, designers can free up capacity for other activities, improve task performance, or achieve the same output with less mental effort.

The contribution of this paper is threefold. Firstly, it adds to the integration of Cognitive Load Theory with studies of method usage in design. Secondly, the results of our analysis provide tentative insight into the relationship between method usage and cognitive efficiency and, thus, take the first step towards identifying mechanisms of managing cognitive load in the increasingly complex challenges designers are called to address. While not conclusive, these trends give insight into an underexplored area of design research. Lastly, by presenting the learnings from this pilot study, we pave the way for better study designs on the influence of design methods on cognitive efficiency. In identifying shortcomings of the chosen measures and overall study setup, we expand on the theoretical understanding of cognitive load and the variables at play concerning method usage, allowing us to suggest improvements for future studies.

7.2 Theoretical Background

7.2.1 Cognitive Load and Design

At the core of designing are cognitive processes that involve, among other aspects, creative thinking, problem-solving, and decision-making (Cross, 2001; Finke et al., 1992; Hay et al., 2017). All design activities build on these fundamental cognitive processes and are essentially the accumulation of cognitive and behavioural actions to achieve a design goal (Bedny & Harris, 2005; Cash & Kreye, 2017, 2018). As a cognitive activity, designing adds to the Cognitive Load of the designer (Lavrsen & Daalhuizen, 2024). Cognitive Load is the strain on cognitive resources when processing information and solving problems (Sweller, 1988; Sweller et al., 2019). It is based on the limited ability to keep relevant information and representations activated and focused in working memory (Hambrick & Engle, 2003; Stanovich, 2009; Sweller et al., 2019).

Similar to design performance generally, Cognitive Load depends on the specific activity, context, and individual (Paas & Van Merriënboer, 1994). Factors like the complexity of the activity or the information needed to be processed, task novelty, time pressure, extreme temperatures, and distractions like noise can increase Cognitive Load (Hancock et al., 2021; Paas & Van Merriënboer, 1994). However, the Cognitive Load experienced by individuals is ultimately subjective and determined by their cognitive capability, knowledge, experience, and familiarity with the activity (Paas & Van Merriënboer, 1994).

7.2.2 Cognitive Efficiency

Cognitive efficiency refers to the optimal utilisation of mental resources to achieve desired outcomes while minimising cognitive load (Paas & Van Merriënboer, 1993). An approach is considered efficient if it results in better performance than what would be expected based on the cognitive effort expended and/or if the expended cognitive effort is lower than might be expected based on the performance (Paas & Van Merriënboer, 1993). Training is the primary way to improve Cognitive efficiency (Chandler, 1993; Paas & Van Merriënboer, 1994; Sweller et al., 2019). Experience improves knowledge structures and makes information processing more efficient (Miller, 1956; Sweller et al., 2019).

Expert designers have been found to structure and organise their cognitive actions more efficiently than novice designers, allowing them to manage and process information more effectively, resulting in higher productivity and better performance in design tasks (Kavakli & Gero, 2002). Similarly, Sun et al. (2014) found that experienced designers are more cognitively efficient than less experienced ones. Moreover, experienced designers deliberately open up the design space, reporting higher levels of Cognitive Load while still outperforming less experienced designers (Sun et al., 2014).

7.2.3 Design Methods and Cognitive Load

As mental tools, design methods scaffold design activities and support learning (Andreasen, 2003; Daalhuizen et al., 2019; Jones, 1992; Royalty, 2018), thereby reducing ineffective load introduced by insufficient knowledge structures and problem-solving strategies (see Xie & Salvendy, 2000). In lieu of training, instructions can, to some extent, stand in for experience (Sweller, 2023). However, for a method to be helpful, the added cognitive load of using it should be offset by a decreased ineffective load or a significant improvement in the output quality (Paas & Van Merriënboer, 1993). Design methods ought to be cognitively efficient as the effort to learn and use a method requires cognitive resources besides those dedicated to the main design task. Using a method should be considered a secondary task, diverting resources away from the main design task (Lavrsen & Daalhuizen, 2024)—at least until the designer has internalised the method (see Daalhuizen, 2014).

Consequently, the *effective cognitive load* required to use a method should be as little as possible. *Effective cognitive load* is the minimal amount of cognitive load required to handle a task under ideal circumstances (Xie & Salvendy, 2000). As such, no amount of training can remove it since it is inherent to the task itself. Part of the *effective load* introduced into the use of a design method might be ascribed to the design and structure of the method content (see Daalhuizen & Cash, 2021). However, in this study, we primarily focus on the underlying mechanisms of systematic versus heuristic approaches and how these influence cognitive efficiency.

7.2.4 Systematic versus Heuristic Design Methods

Design methods can be placed on a spectrum ranging from systematic to heuristic (Daalhuizen, 2014). Methods can thus be categorised based on the amount of information they prescribe to be processed for a task, with more systematic methods aiming to process as much information as possible and heuristic methods limiting the amount of information needed to be processed (Daalhuizen et al., 2014). This difference also reflects that heuristic methods rely more on intuition and expertise and accept satisfactory results, while systematic methods tend towards more deliberate processes aimed at optimal results (Daalhuizen et al., 2014). Both types of methods provide prompts for information processing, aiming to guide the cognitive process of their users (Daalhuizen et al., 2014).

Traditionally, design research has emphasised the development of systematic methods to pursue optimal design processes and practices, as in the case of Pahl et al. (2007). Systematic methods tend to include more systematic and algorithmic procedures (Cross, 2008). They are often hierarchical (Bender & Blessing, 2004), top-down, and prescriptive (Guindon, 1990). They aim to formalise best practices, manage complexity, facilitate teamwork, and limit mistakes in the design process and failures of products (Cross, 2008; Daalhuizen, 2014). However, the emphasis on logical reasoning in systematic methods prompts a problem-focused approach akin to the 'scientific method' rather than the abductive approach characteristic of designers (Cross, 2008; Dorst, 2011; Lawson, 2010). Furthermore, systematic methods tend to be challenging to use in real-world situations (Schønheyder & Nordby, 2018) and seldom reflect how designers really work (Bender & Blessing, 2004; Cross, 2008; Jensen & Andreasen, 2010).

On the other hand, heuristic methods rely on more generalised rules of thumb. They tend to ignore information wilfully to achieve cognitive efficient processes (Daalhuizen, 2014; Gigerenzer & Brighton, 2009), and can generally be seen as cognitive shortcuts (Yilmaz & Seifert, 2011). Using heuristics for design has been found to be an effective way of increasing performance in design activities among novices (Yilmaz et al., 2010). Gigerenzer and Brighton (2009) highlight that heuristics produce better predictions than inductive algorithmic approaches when the sample size is small, and the criterion is uncertain. The less-is-more strategy does so by reducing the variance in decision-making (Gigerenzer & Brighton, 2009).

Consequently, systematic methods introduce a higher cognitive load in the hope of improving performance. To achieve cognitive efficiency, the use of a systematic method thus has to improve performance more than the use of it increases cognitive load. Conversely, heuristic methods aim to achieve cognitive efficiency by minimising the information processing needed without a corresponding reduction in performance.

7.3 Hypotheses

Based on the above, we hypothesise that:

- H1: Cognitive load is higher when using a systematic method over a heuristic method.
- H2: Time spent on the design task will be higher when using a systematic method over a heuristic method.
- H3: Performance on the task will be higher when using a systematic method over a heuristic method.

H4: Cognitive Efficiency will be higher when using a heuristic method over a systematic method.

H5: Cognitive Efficiency will be higher when using a preferred approach over using a systematic or heuristic method.

Because they rely on processing more information, we hypothesise that using a systematic method (Condition 1) will result in a higher cognitive load than using a heuristic method (Condition 2) (H1). Similarly, we hypothesise that Condition 1 will require more time than Condition 2 (H2) and that this additional time will increase performance (H3). Despite increased performance due to time-on-task, we hypothesise that the heuristic method will result in higher cognitive efficiency, assuming that the systematic method will not increase the performance enough to counteract the added cognitive load (H4).

Considering the expertise level of the participants, we also hypothesise that following either of the prescribed methods will be less cognitively efficient than following whatever approach the participant prefers (Condition 3) (H5). The underlying assumption being that, as trained designers, the participants have internalised appropriate design approaches and cognitive strategies that allow them to perform cognitively efficiently on the design task of this study, meaning that following the prescribed methods becomes a secondary task, redirecting cognitive resources from the primary task of concept development (Lavrsen & Daalhuizen, 2024; Xie & Salvendy, 2000).

7.4 Method

Given the complexity of both the phenomenon of method usage (Daalhuizen, 2014), the mechanisms through which creative activities influence cognitive load (Sweller, 2023; Sweller et al., 2019), the limited understanding of how design methods interact with their users (Daalhuizen & Cash, 2021), and the limited research on cognitive load in relation to designers and their activities, we conducted the study not only to test the hypotheses or refine the study design but also to identify potential gaps in both the methodology and theory. As an instrument of inquiry, a pilot study can help uncover patterns, generate new hypotheses, and develop a more nuanced understanding of the relationships between method usage and design performance. As such, the study should be evaluated not only on its ability to yield statistically significant results but also on the learning and theoretical insights it provides to this emerging field of study.

7.4.1 Study Design

To test our hypothesis, we employed an experiment following an independent, single-anonymized, single-factor, three-level experiment design, testing the influence of the three different conditions of the independent variable on the dependent variables. The single factor under investigation in this study is the type of design methods (see ‘Independent variable’ in Figure 7-1). This factor is investigated through three conditions representing different design approaches with varying levels of specified instructions and systematicity, allowing for a precise and controlled examination of the effect of the independent variable on the dependent variable, as shown in Figure 7-1. Being conducted under single-anonymized conditions, the participants were unaware of which condition they were assigned to, minimising potential biases in their responses.

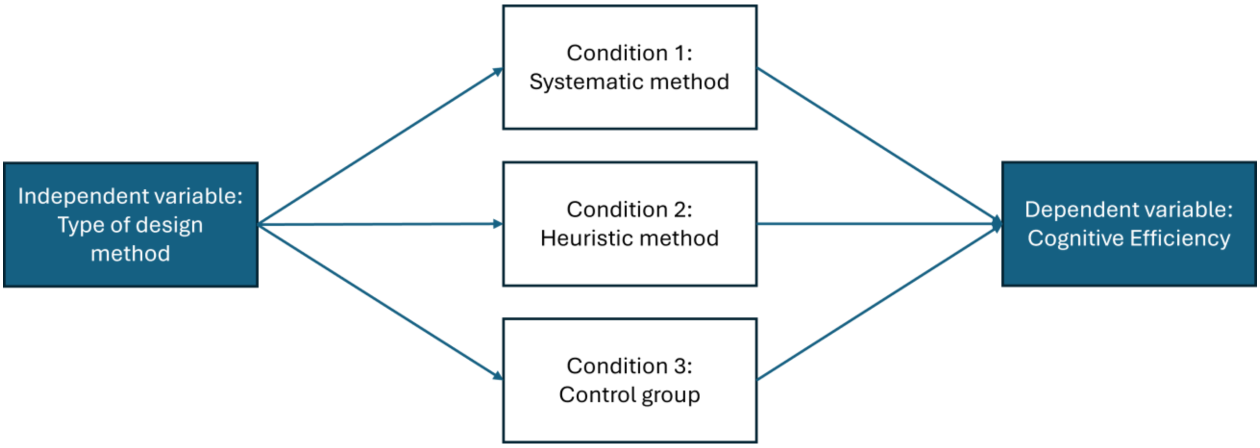


Figure 7-1: Experimental design, indicating the independent variable (Type of method used), the three conditions (using a systematic method, using a heuristic method, and following one's own preference), and that they are expected to influence the dependent variable (cognitive efficiency).

7.4.2 The Independent Variable: Types of Design Methods

To test our hypotheses, three conditions were devised. Conditions 1 and 2 were based on two methods placed on different ends of the systematic-to-heuristic-spectrum, previously used and described by Daalhuizen et al. (2014). Condition 3 has been included to establish a baseline against which the effects of the two other conditions can be evaluated.

7.4.3 Condition 1: Systematic Method

In condition 1, participants were introduced to and asked to use the *morphological analysis* method. *Morphological analysis* breaks down an overall idea into sub-functions for each of which alternative solutions ideas are then generated—reflecting the emphasis on logically deriving specifications from the design problems and analytically evaluating potential solutions characteristic of systematic design methods (Cross, 2008). The method aims to support systematically generating many novel solutions by combining the ideas for solving the sub-functions. As solutions are generated for the sub-problems, the number of combinations and, thus, potential solutions increase exponentially (van Boeijen et al., 2020). However, using the method effectively requires substantial mental effort and discipline, and even so, there is no guarantee of achieving the method's goal of a (near) optimal solution.

7.4.4 Condition 2: Heuristic Method

In condition 2, participants were introduced to and asked to use four heuristics—*Primary Generator*, *Conjecture-analysis*, *Iteration*, and *Satisficing*—strung together to a general process for concept development. The *Primary generator* suggests starting the design process with the most salient problem/sub-problem (Daalhuizen et al., 2014; Darke, 1979). *Conjecture-analysis* prompts a reduction of the design space by essentially framing it by proposing a potential solution and exploring the design space through that lens (Hillier et al., 1972). *Iteration* prompts the continuous revision of prior decisions as the understanding of the design space and its opportunities evolve (Adams & Atman, 1999). Lastly, *Satisficing* functions as a completion criterion. *Satisficing* suggests '...look[ing] for good or satisfactory solutions instead of optimal ones' (Simon, 1996, p. 119) and stopping the design process when a solution meets the design objectives to avoid spending unnecessary time trying to determine if it is the optimal one (Simon, 1996). As such, this method relies on intuition and experience to minimise the information processed while exploring the design space, aiming to reduce cognitive load while still arriving at a satisfying solution.

7.4.5 Condition 3: Control

In condition 3, participants were prompted to choose whatever strategies, heuristics, or design methods they liked to solve the design task, which was inspired by the 'choice condition' in Yilmaz et al.'s (2010) study. In this condition, participants are introduced to the same heuristics and core mechanisms at play in Conditions 1 and 2; however, unlike in Yilmaz et al.'s (2010) study, they were not limited to choose from these, but rather to choose whatever approach they preferred. While the intervention might prompt some to use similar approaches as Conditions 1 and 2, the lack of prescribed methods or instructions on how to use the underlying mechanisms should help us establish a baseline for Cognitive Efficiency when embodied or familiar rather than prescribed methods are used.

7.4.6 The Dependent Variable: Cognitive Efficiency

We have chosen Cognitive Efficiency as our dependent variable. Cognitive Efficiency is a promising measure for a more nuanced evaluation and investigation of how methods function and contribute to design work. This is because it combines both task performance, which is often used in the evaluation of design methods, as well as the measure of Cognitive Load, which provides a measure of how cognitively taxing a designer has experienced the design activity to be.

To measure Cognitive Efficiency (E), we follow the approach of Paas and Van Merriënboer (1993), following the formula: $E = (Z_{Performance} - Z_{Mental\ effort})/\sqrt{2}$, where Z is the standardised score of performance and mental effort, respectively, calculated as the *effort scores* (r) minus the *grand Mean* (*M*), divided by the standard deviation (*SD*; $Z_r = (r - M_r))/SD_r)$). This calculational method gives us the relative condition efficiency, which '...is defined as the observed relation between mental effort and performance in a particular condition relative to a hypothetical baseline condition, in which each unit of invested mental effort equals one unit of performance' (Paas & Van Merriënboer, 1993, p. 739). As such, if E = 0, *cognitive efficiency* aligns with the hypothetical baseline condition, where an increase in performance corresponds to an equal increase in *cognitive load*. A negative score indicates that performance increases less than cognitive load, pointing towards less cognitive efficiency, while a positive score indicates that performance increases more than cognitive load, pointing towards higher cognitive efficiency. Due to the way Cognitive Efficiency is calculated, it becomes negative when Cognitive Load numerically is bigger than performance. Thus, a negative score might still indicate good Cognitive Efficiency relative to alternative approaches to the same task. Cognitive Efficiency has previously been used in relation to design research by Sun et al. (2014, 2015) and Sun & Yao (2012).

7.4.7 Measuring Cognitive Load

For this study, we employed the NASA-TLX (Hart & Staveland, 1988; NASA & Human Performance Research Group, n.d.) to capture the experienced cognitive load associated with the three conditions. The NASA-TLX is a multi-dimensional instrument measuring cognitive load based on six dimensions: Mental demand, Physical demand, Temporal demand, Performance, Effort, and Frustration (Hart, 2006; Hart & Staveland, 1988), and is by far the most used subjective measure of cognitive load (Hancock et al., 2021). In calculating the mental workload, the dimensions are individually weighted to control for variations in understanding of the construct and the dimensions before being added and then divided by 15 to get the overall score (see Hart, 2006; Hart & Staveland, 1988; NASA & Human Performance Research Group, n.d.). The NASA-TLX has the advantage of not interfering with the design process. However, it does not necessarily capture the nuances of cognitive load throughout the process, as we collected the data retrospectively.

7.4.8 Measuring Performance

In general terms, performance can be defined as the effectiveness by which a task is accomplished, as measured by, e.g., quality (Paas & Van Merriënboer, 1993), efficiency, or accuracy (Hancock et al., 2021). Due to the wickedness of design problems, they have no predefined, correct, or even optimal solution (Lavrsen & Daalhuizen, 2024; Rittel & Webber, 1973), which makes it challenging to measure performance in terms of efficiency or accuracy. As we have no standards to rely on, we use and compare four measures of performance in this pilot study. First, three self-assessed measures concerning the participants' perceived novelty and usefulness of their solutions and their satisfaction with the produced solution, measured by a single item rated on a 7-point Linkert scale ranging from Disagree (1) to Agree (7)(see Table 7-1). Second, one rater-assessed measure of how well the proposed solution solved the problems stated in the brief (*Resolution of Problem*). This approach was inspired by Sun et al. (2014), and is based on requirements derived from the design brief. *Resolution of Problem* was assessed based on four requirements (see Table 7-1), rated on a 7-point Linkert scale going from *Disagree* (1) to *Agree* (7), by the first author and an innovation consultant, both with experience assessing early-stage design ideas. The scores for each requirement and rater were averaged to provide a single measure of how well the problems presented in the brief had been resolved.

Table 7-1: The performance measures, the items used to rate them (on a 7-point Linkert scale), and the type of assessment

Type of assessment	Performance measures	Items
Self-assessed	Self-assessed Novelty Self-assessed Usefulness Satisfaction with solution	My concept is NOVEL (original) compared to other existing solutions I know of My concept is USEFUL compared to other existing solutions I know of I am satisfied with the quality of my solution
Rater-assessed	Resolution of Problem	The solution is easy to carry The solution enables impaired people to open and lock their doors The solution minimises the risk of losing keys The solution limits the struggle to find the correct key

The inter-rater reliability was assessed based on the two independent raters' evaluation of a subset of 13 out of the 44 cases (30 %). The remaining cases were rated only by the first author. Given the small sample size and the ordinal nature of the data, Krippendorff's Alpha was chosen to assess the inter-rater reliability. The inter-rater reliability, $\alpha = 0.713$, SE = 0.192, indicated an agreement acceptable for drawing tentative conclusions ($0.66 > \alpha < 0.80$; Krippendorff, 2004), which is sufficient for the purposes of a pilot study like the one here.

7.4.9 Participants

Participants were recruited from a master's course on facilitation of innovation at the Technical University of Denmark (DTU). To be eligible for the course, students must have completed two courses in entrepreneurship, design, innovation, product development, or project management, ensuring some familiarity with concept development. Of the 52 participants, 44 completed the survey (response rate 85%). Table 7-2 shows the demographic data and how the participants were split between the three conditions.

Table 7-2: Demographic data of the Participants and their split into the conditions (Number, age, gender, experience)

	Participants	Average age	Gender (female/male)	Courses incl. concept development	Practical experience (months)
Condition 1 (Systematic)	12	25.3 (*SD* = 1.87)	8/4	7.1 (*SD* = 5.90)	6.7 (*SD* = 8.77)
Condition 2 (Heuristic)	16	25.2 (*SD* = 2.43)	5/11	7.8 (*SD* = 6.25)	9.8 (*SD* = 13.19)
Condition 3 (Control)	16	26.1 (*SD* = 4.19)	7/9	4.4 (*SD* = 4.18)	7.6 (*SD* = 13.24)
Overall	44	25.5 (*SD* = 3.04)	20/24	6.4 (*SD* = 5.56)	8.2 (*SD* = 11.97)

7.4.10 Procedure

The data was collected through an electronic survey as part of a lecture in the abovementioned course. Participants were physically present in the classroom and were given a link, sending them randomly to one of three versions of an online survey representing the three conditions with no knowledge of either condition or the specific focus of the study. Following a funnelled debrief approach to reduce *demand characteristics* (Eysenck, 2009), we limited the information revealed to the participants to what they needed to know at each stage of the experiment. The survey was designed to guide them through the experiment and collect data with no additional contact with the researchers, and as such, secure standardisation and limit experimenter bias.

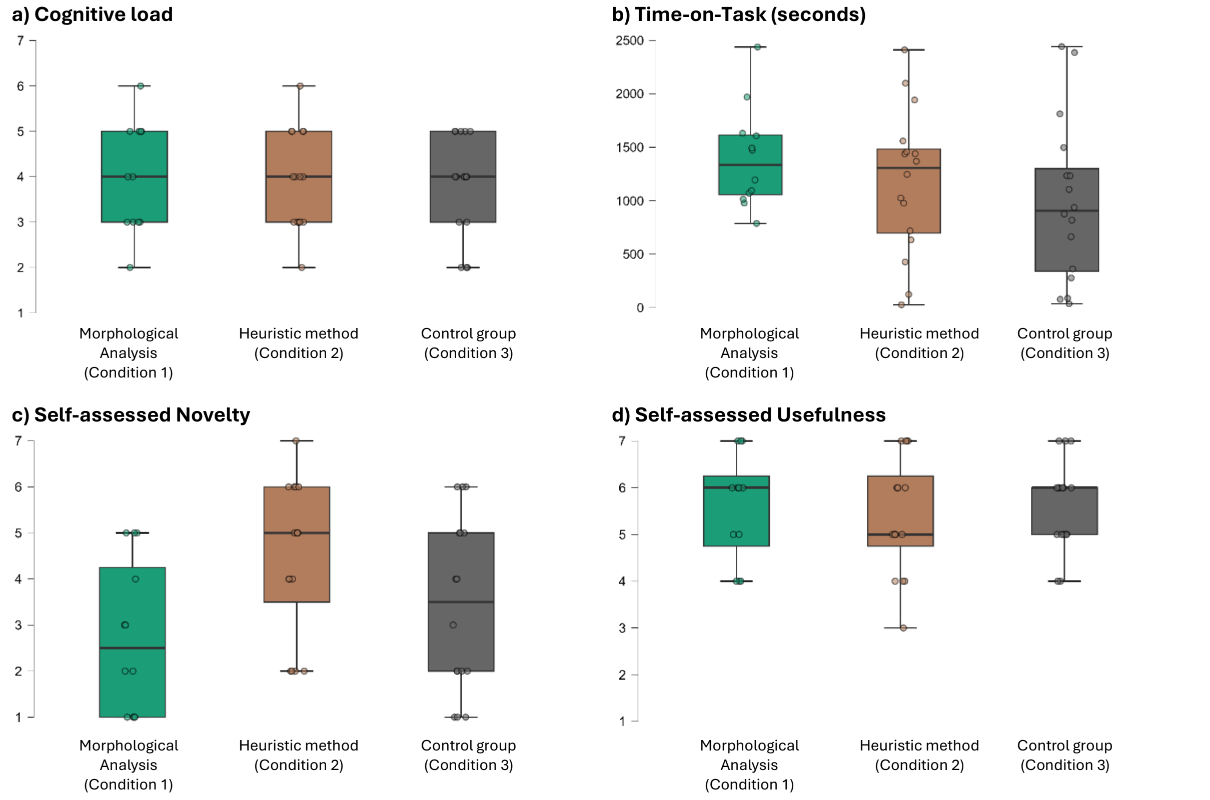
After collecting consent for participation and being given general instructions about the procedure, the participants were presented with their experimental condition, having the time to read and familiarise themselves with the methods or, in the case of the control group, read a general text about differences in approaches to idea generation. Next, the participants were given a maximum of 40 minutes to read the design brief and generate design concepts according to their assigned conditions. By introducing the conditions before the design brief, the participants could not start generating solutions while familiarising themselves with their method, thus ensuring similar time for concept development across the conditions regardless of prior experience with the method. We used a slightly adapted version of the design brief presented by Daalhuizen et al. (2014), which asked participants to create 'a concept for a tangible product that helps older people handle and manage their keys' (Daalhuizen et al., 2014, p. 153). All participants were provided with blank A3-size sheets of paper to help facilitate the concept development. Directly following the completion of the design task, the participant filled in the NASA-TLX. Afterward, the participants were given ten minutes to describe their concepts in more detail. The time limit was set to reduce any concept development prompted by the survey questions rather than the conditions. Similarly, it was placed after the NASA-TLX to avoid influencing the measure of cognitive load related to the experimental conditions. Lastly, demographic data and additional information were gathered to assess the influence of potential confounding variables.

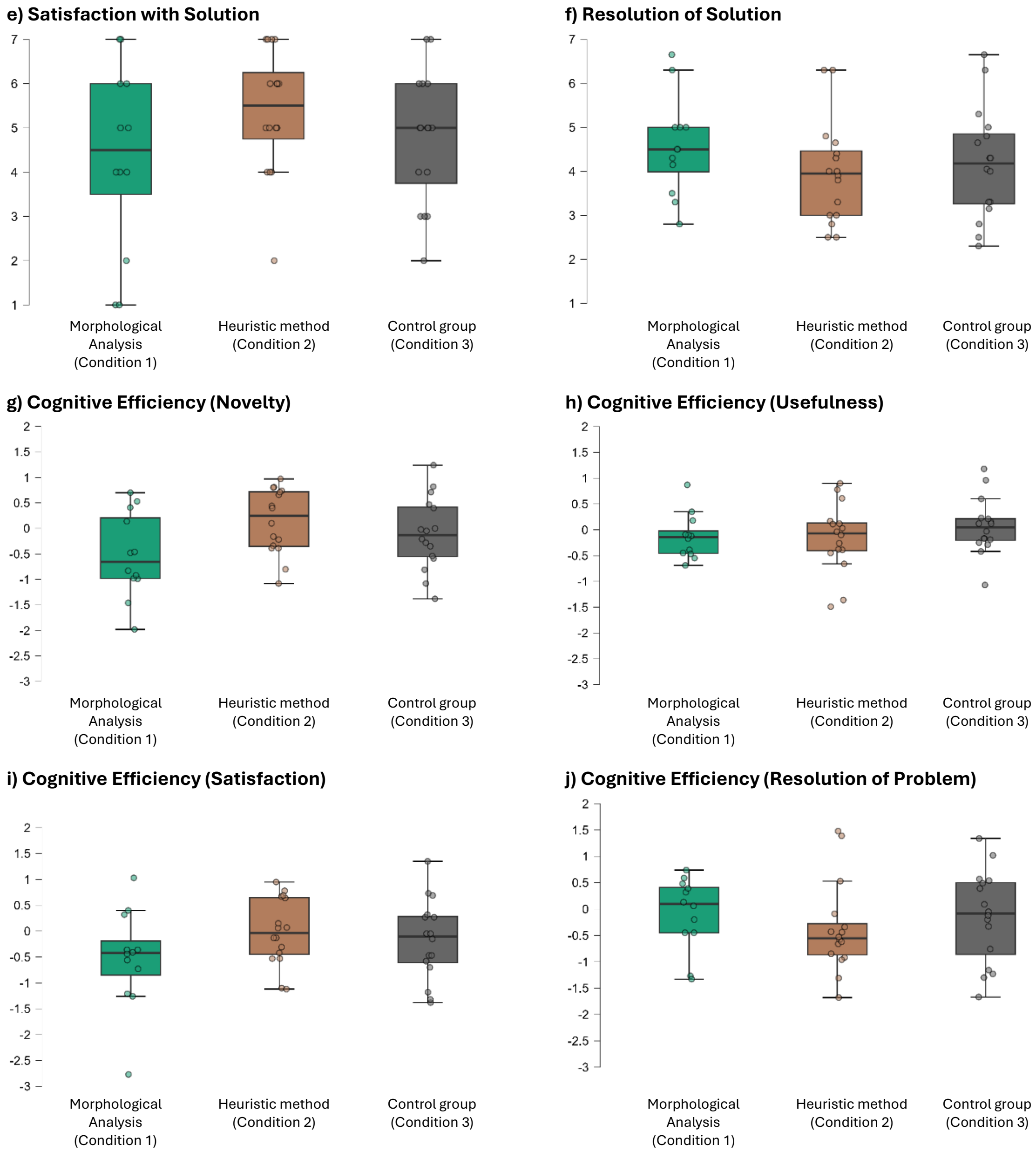
7.5 Data Analysis and Results

Forty-four entries were included for analysis. Eight incomplete entries were removed from the dataset. Next, the *Resolution of Problem* was rated, and the Cognitive Efficiency scores were calculated based on the four performance measures.

The data is generally normally distributed (Shapiro-Wilk's $p > .05$) when considered separately for the three conditions. The exceptions are the control condition (C3) for *Weighted NASA-TLX* (Shapiro-Wilk's $p = 0.010$) and *Self-assessed Novelty* (Shapiro-Wilk's $p = 0.039$) and the use of the heuristic method (C2) for *Cognitive Efficiency* (*Resolution of Problem;* Shapiro-Wilk's $p = 0.042$). The data are visually represented in Figure 7-2, showing the boxplots for each dependent variable across the three conditions.

FIGURE 7-2: BOXPLOTS FOR EACH DEPENDENT VARIABLE SHOWING SCORES ACROSS THE THREE CONDITIONS





7.5.1 Testing the Hypothesis (ANCOVAs)

Ten ANCOVAs, using different dependent variables, were conducted to test the hypothesis and evaluate the differences between the three conditions. Three covariates—feeling of having the *Necessary skills*, *Familiarity with method,* and *Practical experience*—were included to control for experience and familiarity with the task. Other covariates were tested but not included, as they had no significant influence on any of the analyses. Assumptions test, testing for homogeneity, and normal distributions of residuals were run for all analyses. The Homogeneity tests showed that the variance of the dependent variable is equal across the conditions (Levene's $p > 0.05$). Similarly, the residuals were found to be normally distributed based on visual assessment of the Q-Q plots. Consequently, we assessed the data to be acceptable for the intended analysis.

7.5.2 Cognitive Load (H1)

As indicated by Figure 7-2a, the scores on Cognitive load across the three conditions were very similar (Condition 1: $M = 4.0$, $SD = 1.2$; Condition 2: $M = 3.9$, $SD = 1.1$; Condition 3: $M = 3.8$, $SD = 1.1$), which is also reflected in the ANCOVA, not finding any statistically significant difference ($p > .05$) between them ($p = 0.988$, $\omega^2 < .0001$; Table 7-3). It is worth noting that the feeling of having the *Necessary skills* had a significant effect on *cognitive load*, suggesting that despite our attempts to ensure homogeneity in the sample, levels of expertise might still influence our results generally.

Table 7-3: ANCOVA - Differences in Cognitive Load across conditions (H1)

Cases	Sum of Squares	*df*	Mean Square	*F*	*p*	ω^2
CONDITION	0.030	2	0.015	0.013	0.988	<.001
Necessary skills	6.376	1	6.376	5.425	0.025*	0.099
Familiarity with method	0.164	1	0.164	0.140	0.710	<.001
Practical experience	0.139	1	0.139	0.119	0.732	<.001
Residuals	44.663	38	1.175			

Note. Type III Sum of Squares
* $p < .05$.

While the lack of statistical significance and the effect size (ω^2) suggest that it might be due to random variation and, thus, provide insufficient evidence for either accepting or rejecting the hypothesis, the results align with Hypothesis 1 with the use of *morphological analysis* (C1) inducing more *cognitive load* than using the heuristic method (C2). The control group (C3) reported the lowest cognitive load, supporting the idea that method usage is a secondary task requiring additional cognitive effort. As indicated by the Post Hoc Test (Table 7-4), even when adjusted for the covariates, this pattern remains the same.

Table 7-4: Post Hoc Test (Standard (LSD)) - Differences in conditions (cognitive load)

		Mean Difference	*SE*	*t*	p_{tukey}
Control*	Heuristic	-0.049	0.391	-0.126	0.991
Control*	Morphological	-0.065	0.451	-0.145	0.988
Heuristic*	Morphological	-0.016	0.431	-0.037	0.999

Note. P-value adjusted for comparing a family of 3
* best performing condition

7.5.3 Time-on-Task (H2)

Figure 7-2b indicates that data aligns with Hypothesis 2, with more time spent on idea generation when using the *morphological analysis* (C1: *M* = 1395.833 s, or 23 min. 16 s, *SD* = 472.960 s), than using the heuristic method (C2: *M* = 1180.688 s, or 19 min. 41 s, *SD* = 679.663 s), and least time spent when not being bound to use a specific method (C3: *M* = 990.250 s or 16 min. 30 s, *SD* = 763.002 s). The additional time spent following a prescribed method compared to when not; again supports the idea that method usage is a secondary task. However, the difference could also be an expressing of less effort used, which also would align with the lower cognitive load reported above. It might also come down to different methods engaging the method user for different amounts of time.

While the difference between the conditions is visually clearer than for cognitive load (see Figure 7-2a and b), the ANCOVA finds that the difference in time spent on the task is not statistically significant (*p* = 0.116), and the small effect size (ω^2 = 0.055) is too low to determine if the conditions can explain the variance between them (see Table 7-5). Similarly, none of the included covariates influences the difference significantly, which is why the relationship between the conditions remains the same after adjusting the means (see Table 7-6).

Table 7-5: ANCOVA - Differences in Time-on-Task across conditions (H2)

Cases	Sum of Squares	*df*	Mean Square	*F*	*p*	ω^2
CONDITION	$1.875\times10^{+6}$	2	937476.745	2.279	0.116	0.055
Necessary skills	6910.475	1	6910.475	0.017	0.898	<.001
Familiarity with method	$1.057\times10^{+6}$	1	$1.057\times10^{+6}$	2.570	0.117	0.033
Practical experience	319314.181	1	319314.181	0.776	0.384	<.001
Residuals	$1.563\times10^{+7}$	38	411344.185			

Note. Type III Sum of Squares

Table 7-6: Post Hoc Test (Standard (LSD)) - Differences in conditions (Time-on-Task)

		Mean Difference	*SE*	*t*	p_{tukey}
Control	Heuristic	-235.041	231.268	-1.016	0.571
Control	Morphological	-569.634	266.821	-2.135	0.096
Heuristic	Morphological	-334.593	254.894	-1.313	0.397

Note. P-value adjusted for comparing a family of 3.

7.5.4 Performance (H3)

We analyse four different measures of performance: *Self-assessed Novelty, Self-assessed Usefulness, Satisfaction with the solution*, and *Resolution of Problem*.

7.5.4.1 Self-assessed novelty (H3a)

As seen in Figure 7-2c, *Self-assessed Novelty* was scored highest when using the heuristic method (C2: *M* = 4.438, *SD* = 1.672). This goes against Hypothesis 3, expecting using the *morphological analysis* (C1: *M* = 2.750, *SD* = 1.658) to result in the best performance. Interestingly, the control group (C3: *M* = 3.438, *SD* = 1.896) also outperforms the use of the morphological analysis (C1), indicating that the higher *cognitive load* and *time-on-task* resulting from using the *morphological analysis* does not translate into performance or a high *Self-assessed Novelty*, to be more precise. As is the pattern for this pilot study, the ANCOVA (Table 7-7) finds that the difference between the three conditions is not statistically significant (p = 0.078, ω^2 = 0.077).

Table 7-7: Post Hoc Test (Standard (LSD)) - Differences across conditions (Performance (Novelty))

		Mean Difference	*SE*	*t*	p_{tukey}
Control	Heuristic*	-1.053	0.652	-1.614	0.252
Control*	Morphological	0.526	0.753	0.698	0.766
Heuristic*	Morphological	1.578	0.719	2.195	0.085

Note. P-value adjusted for comparing a family of 3
* best performing condition

7.5.4.2 Self-assessed usefulness (H3b)

While the difference is less pronounced, Figure 7-2d suggests that the scores on *Self-assessed usefulness* across the three conditions is in alignment with Hypothesis 3. Using *morphological analysis* (C1) resulted in a higher assessment of usefulness (*M* = 5.583, *SD* = 1.165) than when using the heuristic method, (C2: *M* = 5.375, *SD* = 1.258). However, when controlling for the covariates, using the heuristic method ends up outperforming using *morphological analysis* (Adj. $M\Delta$ = 0.020; see Table 7-9), suggesting that Hypothesis 3 needs to be rejected. The control group (C3: *M* = 5.625, *SD* = 0.957) outperformed both of the other conditions. Similar to the above, the ideas generated might not actually be more useful. As a self-assessed measure, it could just be that the different conditions influence how the participant perceives the usefulness of an idea.

Once again, the differences are not statistically significant and with no measurable effect according to the ANCOVA (p = 0.665; ω^2 < .0001; see Table 7-8), suggesting that the alignment with the hypothesis might be a coincidence due to random variation. However, the feeling of having had the *Necessary skills* is again having a significant effect on the assessment of usefulness.

Table 7-8: ANCOVA - Differences in performance (Usefulness) across conditions (H3b)

Cases	Sum of Squares	*df*	Mean Square	*F*	*p*	ω^2
CONDITION	0.875	2	0.437	0.412	0.665	<.001
Necessary skills	11.611	1	11.611	10.932	0.002*	0.188
Familiarity with method	1.601	1	1.601	1.507	0.227	0.010
Practical experience	0.671	1	0.671	0.631	0.432	<.001
Residuals	40.363	38	1.062			

Note. Type III Sum of Squares
* p < .05.

TABLE 7-9: POST HOC TEST (STANDARD (LSD)) - DIFFERENCES ACROSS CONDITIONS (PERFORMANCE (USEFULNESS))

		Mean Difference	*SE*	*t*	p_{tukey}
Control*	Heuristic	0.301	0.372	0.811	0.699
Control*	Morphological	0.321	0.429	0.749	0.736
Heuristic*	Morphological	0.020	0.410	0.049	0.999

Note. P-value adjusted for comparing a family of 3
* best performing condition

7.5.4.3 Satisfaction with the solution (H3c)

Figure 7-2e shows that *Satisfaction with the solution* follows the same pattern as *Self-assessed Novelty* (Figure 7-2c). Using the heuristic method (C2) results in the highest satisfaction with the solution (*M* = 5.375, *SD* = 1.408), which is at odds with Hypothesis 3. Like *Self-assessed novelty* as well, the control group (C3: *M* = 4.750, *SD* = 1.483) outperformed the participants using the *morphological analysis* (C1: *M* = 4.333, *SD* = 2.103). Similar to *Self-assessed novelty*, this might indicate that using the heuristic approach positively influences the experienced satisfaction with the solution, if not the actual performance.

Considering the ANCOVA (Table 7-10), any conclusions should, however, be made with caution, as the results might be due to random variance ($p = 0.251$, $\omega^2 = 0.032$). *Necessary skills* again seem to affect the dependent variable significantly ($p = 0.018$, $\omega^2 = 0.104$), but not enough to influence the reported relationships between the conditions (see Table 7-11).

TABLE 7-10: ANCOVA - DIFFERENCES IN PERFORMANCE (SATISFACTION) ACROSS (H3C)

Cases	Sum of Squares	*df*	Mean Square	*F*	*p*	ω^2
CONDITION	8.494	2	4.247	1.773	0.184	0.032
Necessary skills	14.536	1	14.536	6.067	0.018*	0.104
Familiarity with method	0.033	1	0.033	0.014	0.907	<.001
Practical experience	0.033	1	0.033	0.014	0.907	<.001
Residuals	91.039	38	2.396			

Note. Type III Sum of Squares
* $p < .05$.

TABLE 7-11: POST HOC TEST (STANDARD (LSD)) - DIFFERENCES ACROSS CONDITIONS (PERFORMANCE (SATISFACTION))

		Mean Difference	*SE*	*t*	p_{tukey}
Control	Heuristic*	-0.609	0.558	-1.091	0.526
Control*	Morphological	0.525	0.644	0.816	0.696
Heuristic*	Morphological	1.134	0.615	1.843	0.169

Note. P-value adjusted for comparing a family of 3
* best performing condition

7.5.4.4 Resolution of Problem (H3d)

Figure 7-2f indicates that using *morphological analysis* (C1) resulted in the highest scores of *Resolution of Problem* (*M* = 4.583, *SD* = 1.129), outperforming the participants using the heuristic method (C2, *M* = 3.972, *SD* = 1.165) in alignment with Hypothesis 3. Considering the nature of the measure, the results could indicate that using *morphological analysis* helps the method user consider more components of the problem space, generating ideas that address more aspects of the design brief, which would align with the method's focus of identifying subproblems or -functions.

Again, the ANCOVA (Table 7-12) found no statistical significance ($p = 0.450$, $\omega^2 < .0001$) indicates that the difference might be the result of random variance. Interestingly, this rater-assessed measure is affected by all the covariates, suggesting that expertise plays a bigger *role in the more objective assessment of performance. As such, while the control group (C3: M* = 4.169, *SD* = 1.267) seem to be outperformed by the use of *morphological analysis* (C1), the Post Hoc analysis (Table 7-13) show that, when adjusted for the covariates, the control group outperforms Condition 1 (Adj. *MΔ* = 0.162).

Table 7-12: ANCOVA - Differences in performance (Resolution of Problem) across conditions (H3d)

Cases	Sum of Squares	df	Mean Square	F	p	ω^2
CONDITION	1.801	2	0.901	0.817	0.450	<.001
Necessary skills	6.232	1	6.232	5.650	0.023*	0.075
Familiarity with method	12.737	1	12.737	11.548	0.002*	0.170
Practical experience	4.773	1	4.773	4.328	0.044*	0.054
Residuals	41.913	38	1.103			

Note. Type III Sum of Squares
* *p* < .05.

Table 7-13: Post Hoc Test (Standard (LSD)) - Differences across conditions (Performance (Resolution of problem))

		Mean Difference	SE	t	p_{tukey}
Control*	Heuristic	0.473	0.379	1.250	0.432
Control*	Morphological	0.162	0.437	0.371	0.927
Heuristic	Morphological*	-0.311	0.417	-0.746	0.738

Note. P-value adjusted for comparing a family of 3
* best performing condition

7.5.5 Cognitive Efficiency (H4-H5)

In the following, we analyse the difference in cognitive efficiency calculated based on the four performance measures and cognitive load across the conditions. As a result of the very similar scores of *cognitive load* across the conditions, the relationship between the measures of *cognitive efficiency* and the conditions follows the same pattern as the performance measures analysed above, the conclusion is, however, different.

7.5.5.1 Self-assessed Novelty (H4a and H5a)

Figure 7-2g, indicate that Hypothesis 4 holds true for *cognitive efficiency* based on the *Self-assessed* Novelty, while Hypothesis 5 is violated. Using the heuristic method (C2) resulted in the highest *cognitive efficiency* (*M* = 0.141, *SD* = 0.636), outperforming both the use of *morphological analysis* (C1: *M* = -0.527, *SD* = 0.831) and the control group (C3: *M* = -0.104, *SD* = 0.709). These relationships remain the same after controlling for the covariates (Table 7-15). Only the use of the heuristic method achieved a *cognitive efficiency* (E) above the hypothetical baseline for *cognitive efficiency* (E = 0), suggesting that the other conditions might be cognitively inefficient, requiring relatively more cognitive effort to achieve similar levels of performance.

Following the same pattern as the other results, the differences between the conditions are not statistically significant (*p* = 0.130) with only a limited effect size (ω^2 = 0.052*;* see Table 7-14).

Table 7-14: ANCOVA - Differences in cognitive efficiency (Novelty) across conditions (H4a and H5a)

Cases	Sum of Squares	df	Mean Square	F	p	ω^2
CONDITION	2.333	2	1.166	2.157	0.130	0.052
Necessary skills	0.634	1	0.634	1.172	0.286	0.004
Familiarity with method	0.138	1	0.138	0.256	0.616	<.001
Practical experience	0.054	1	0.054	0.099	0.755	<.001
Residuals	20.551	38	0.541			

Note. Type III Sum of Squares

Table 7-15: Post Hoc Test (Standard (LSD)) - Differences across conditions (Cognitive efficiency (Novelty))

		Mean Difference	SE	t	p_{tukey}
Control	Heuristic*	-0.260	0.265	-0.982	0.593
Control*	Morphological	0.345	0.306	1.127	0.504
Heuristic*	Morphological	0.605	0.292	2.070	0.110

Note. P-value adjusted for comparing a family of 3
* best performing condition

7.5.5.2 Self-assessed Usefulness (H4b and H5b)

Figure 7-2h suggests that the results support both Hypotheses 4 and 5. The control group (C3: *M* = 0.062, *SD* = 0.537) outperforms the two other conditions, aligning with Hypothesis 5. While the median, as shown in Figure 7-2h, suggest that the participants using the heuristic method are achieving higher cognitive efficiency (C2: Md = -0.070) than those using *morphological analysis* (C1: Md = -0.145), the means suggest the opposite (C1: *M* = -0.136, *SD* = 0.438; C2: *M* = -0.151, *SD* = 0.662). However, when controlled for the covariates, the participants using the heuristic method are actually more cognitively efficient than those using *morphological analysis* (see Table 7-17), aligning with Hypothesis 4. Only the control group outperformed the hypothetical baseline for *cognitive efficiency*. Again, the ANCOVA (Table 7-16) shows that the differences are not statistically significant (p = 0.399, ω^2 < 0.001).

Table 7-16: ANCOVA - Differences in cognitive efficiency (Usefulness) across conditions (H4b and H5b)

Cases	Sum of Squares	*df*	Mean Square	*F*	*p*	ω^2
CONDITION	0.621	2	0.311	0.941	0.399	<.001
Necessary skills	0.363	1	0.363	1.098	0.301	0.002
Familiarity with method	0.254	1	0.254	0.769	0.386	<.001
Practical experience	0.038	1	0.038	0.115	0.737	<.001
Residuals	12.546	38	0.330			

Note. Type III Sum of Squares

Table 7-17: Post Hoc Test (Standard (LSD)) - Differences across conditions (Cognitive efficiency (Usefulness))

		Mean Difference	*SE*	*t*	p_{tukey}
Control*	Heuristic	0.237	0.207	1.143	0.494
Control*	Morphological	0.291	0.239	1.217	0.451
Heuristic*	Morphological	0.054	0.228	0.237	0.969

Note. P-value adjusted for comparing a family of 3
* best performing condition

7.5.5.3 Satisfaction with the solution (H4c and H5c)

Figure 7-2i indicates that Hypothesis 5 can be rejected, as the participants using the heuristics method (C2: *M* = -0.016, *SD* = 0.643) outperform the control group (C3: *M* = -0.170, *SD* = 0.773). Using the heuristics method (C2) also outperforms the participants using *morphological analysis* (C1: *M* = -0.529, *SD* = 0.961), supporting Hypothesis 4.

Like the previous results, the ANCOVA (Table 7-18) shows that the differences are not statistically significant (p = 0.236), and the effect size (ω^2 = 0.022) suggests they can be due to random variance, providing little ground for assessing the validity of the hypothesis. Table 7-19 shows that the relationships between the conditions remain the same after controlling for the covariates.

Table 7-18: ANCOVA - Differences in cognitive efficiency (Satisfaction) across conditions (H4c and H5c)

Cases	Sum of Squares	*df*	Mean Square	*F*	*p*	ω^2
CONDITION	1.789	2	0.894	1.402	0.258	0.019
Necessary skills	0.701	1	0.701	1.099	0.301	0.002
Familiarity with method	0.005	1	0.005	0.007	0.933	<.001
Practical experience	0.047	1	0.047	0.074	0.787	<.001
Residuals	24.233	38	0.638			

Note. Type III Sum of Squares

Table 7-19: Post Hoc Test (Standard (LSD)) - Differences across conditions (Cognitive efficiency (Satisfaction))

		Mean Difference	*SE*	*t*	p_{tukey}
Control	Heuristic*	-0.143	0.288	-0.498	0.873
Control*	Morphological	0.385	0.332	1.159	0.485
Heuristic*	Morphological	0.528	0.317	1.665	0.232

Note. P-value adjusted for comparing a family of 3
* best performing condition

7.5.5.4 Resolution of Problem (H4d and H5d)

Figure 7-2j suggests that neither Hypotheses 4 nor 5 can be accepted. The means indicate that using *morphological analysis* (C1: *M* = -0.083, *SD* = 0.684) outperform both the control group (C3: *M* = -0.149, *SD* = 0.879) and the participants using the heuristic method (C2: *M* = -0.376, *SD* = 0.861). However, when controlling for the covariates (see Table 7-20), the control group (C3) becomes the most cognitively efficient (see Table 7-21), aligning with Hypotheses 5.

Similar to the above ANCOVAs, the results are not statistically significant (p = 0.365), and the effect size (ω^2 = 0.001) suggests the differences can be due to random variance (see Table 7-20). While not all the covariates affecting the measures used to calculate *cognitive efficiency* (*Resolution of Problem*) have a significant effect, *Familiarity with method* still has (p = 0.009, ω^2 = 0.125), suggesting that prior experience with a method influences *cognitive efficiency*.

Table 7-20: ANCOVA - Differences in cognitive efficiency (Resolution of Problem) across conditions (H4d and H5d)

Cases	Sum of Squares	*df*	Mean Square	*F*	*p*	ω^2
CONDITION	1.207	2	0.604	1.034	0.365	0.001
Necessary skills	0.488	1	0.488	0.836	0.366	<.001
Familiarity with method	4.460	1	4.460	7.640	0.009*	0.125
Practical experience	2.057	1	2.057	3.524	0.068	0.048
Residuals	22.182	38	0.584			

Note. Type III Sum of Squares

Table 7-21: Post Hoc Test (Standard (LSD)) - Differences across conditions (Cognitive efficiency (Resolution of problem))

		Mean Difference	*SE*	*t*	p_{tukey}
Control*	Heuristic	0.395	0.275	1.432	0.335
Control*	Morphological	0.256	0.318	0.806	0.702
Heuristic	Morphological*	-0.138	0.304	-0.456	0.892

Note. P-value adjusted for comparing a family of 3
* best performing condition

7.6 Discussion

This pilot study has investigated the *cognitive efficiency* related to using systematic and heuristic design methods, focusing on four different measures of performance: *Self-assessed Novelty, Self-assessed Usefulness, Satisfaction with solution*, and the *Resolution of Problem*, in an attempt to assess the theoretical framing, and the strengths and weaknesses of the study design.

Hypothesis 1 and 2, related to *cognitive load* and *Time-on-Task*, matched the measured scores. However, there was practically no difference in *cognitive load* between the three conditions. When controlled for the three covariates—feeling of having the *Necessary skills*, *Familiarity with method,* and *Practical experience*—only the rater-assessed performance measure, *Resolution of problem*, aligned with Hypothesis 3. The data in the case of *cognitive efficiency* calculated based on *Self-assessed Novelty*, *Self-assessed Usefulness,* and *Satisfaction with Solution*, aligned with Hypothesis 4. For Hypothesis 5, this was only the case for *cognitive efficiency* calculated based on *Self-assessed Usefulness* and *Resolution of Problem*. However, when considering the similar scores in *cognitive load* across all conditions (see Figure 7-2a) and the performance measures reported in Section 7.5.4, the alignment with Hypotheses 4 and 5 seems to be driven by the performance and not differences in cognitive load as we hypothesised. Consequently, even though the data aligns with Hypothesis 4 and 5, it does not do so as a result of the expected influence of method usage on *cognitive efficiency*.

Tallying which condition outperformed which across the post hoc tests shows that the control group outperformed the other condition in 14 cases. Using the heuristic method was most beneficial in 11 cases, and using *morphological analysis* only outperformed the other two in 2 cases. *Time-on-Task* has been excluded from the tally since the time spent on the task cannot necessarily be said to be good or bad. The control group consistently outperforms using *morphological analysis* (9 out of 9 cases) but only using the heuristic method in 5 out of 9 cases. Using the heuristic method outperforms using *morphological analysis* in 7 out of 9 cases.

These results seem to indicate that the participants did not generally benefit from using the prescribed methods, aligning with the underlying assumption behind Hypothesis 5, that the participants had sufficient training not to need the help of design methods. However, the lack of statistical significance can also suggest that the methods used may not have had a meaningful impact on performance or *cognitive load*. The inconclusive result generally warrants caution in interpretation, as the study design, sample size, or measurement sensitivity might have been insufficient to detect the differences.

Consequently, the results also suggest the need for improving the precision and reliability of the measurement tools. Reducing measurement error, noise, and random variance has the potential to increase the observed effect size, making the effects clearer and potentially improving the statistical significance of the results.

7.6.1 Sample

As a pilot study, the small sample size imposed a significant limitation of the study, likely contributing to the lack of significant findings. A power analysis suggests that a total sample size of between 119 and 9629, depending on the measure, would be needed to achieve adequate power (0.80) to detect meaningful effects based on the current effect sizes reported. Therefore, future research should aim to include a larger sample size. Even so, a larger sample size is unlikely to reveal significant effects of the conditions in relation to *cognitive load, Self-assessed Usefulness, Resolution of Problem,* and *Cognitive Efficiency (Usefulness)*, which all were found to have an effect size of zero, indicating no detectable differences across conditions. Similarly, *Cognitive Efficiency (Resolution of Problem)* requiring a sample of 9629 participants to ensure adequate power also indicates how little the effect detected here was.

7.6.2 Capturing Cognitive Load

Based on the overlap between Daalhuizen et al.'s (2014) findings of users using *morphological analysis* experiencing higher time pressures, lower motivation, spending more effort, and feeling less effective, and the components of the NASA-TLX, we expected a significantly higher *cognitive load* for condition 1. However, this difference never materialised in the study, suggesting a significant problem with our theoretical conception of how different types of design methods would influence cognitive load or our study design. Either the conditions had no effect, or we failed to capture it.

Looking at the measure of *cognitive load*, it seems unlikely that the lack of differences should be entirely due to a failure of the measure, considering that the NASA-TLX is generally considered a reliable measure of mental effort (Hancock et al., 2021; Hart, 2006). However, there are ways we could improve the sensitivity of how we measure *cognitive load*. For example, by using a secondary task measure of *cognitive load*, like reaction time for turning off an 'alarm'. This would ensure an objective measure of *cognitive load* that could be captured at several points throughout the design task. Combined with responding to a unidimensional subjective measure of cognitive load, like the *Rating Scale Mental Effort* (Zijlstra, 1993), to turn off the 'alarm,' we would have two complementary measures, providing a more nuanced and sensible measure, more susceptible to smaller variations, which should help increase the effect size.

From the theoretical perspective, the lack of effect could be explained in several ways. For example, the participants could be reinvesting any cognitive capacity freed up by the method usage into the idea generation. If so, the measure of *cognitive load* closer resembles the cognitive effort the participants were willing to invest than the cognitive load induced by the interventions, potentially obscuring any effects of using the specific methods. To assess whether this is the case, a measure of motivation could potentially be included in future experiments.

An alternative explanation could be that the participants, as master students, already had internalised the prescribed methods and, therefore, applied them with the same efficiency as they would a method of their own choice. This would suggest that the *effective cognitive load* of all interventions is the same, which seems unlikely considering the different nature of each condition. A more likely interpretation is that the participants only actually followed the prescribed methods to some extent and instead defaulted to other, more familiar strategies in alignment with taking an opportunistic approach (see Bender & Blessing, 2004) similar to that of the control group, explaining why there is no significant difference between the conditions. This would again mean that our measure does not capture the cognitive load related to the intervention but rather the *cognitive efficiency* of the participant.

To mitigate the confounding variables resulting from such deviations from the prescribed methods of Condition 1 and 2, the experiment could be conducted with participants with less design and innovation experience since they would be less likely to identify or abandon the relative safety of following a method to pursue opportunities (Bender & Blessing, 2004). Furthermore, participants with less design training should benefit more from using design methods, as they are less likely to have internalised efficient design approaches. Theoretically, a relatively more complex or difficult design task should increase the impact of method usage, as it would require higher cognitive efficiency to avoid cognitive overload when solving it (Lavrsen & Daalhuizen, 2024). Increasing the intensity of the intervention has the added benefit of increasing the observed effect of the intervention, thus helping to address to low effect sizes reported in this study. An alternative way to address the deviations from the prescribed methods would be to record and analyse the method usage to develop a protocol to determine the degree to which the method was followed, as is often done in experiments in design research (Bilda & Gero, 2007; Cross, 2001; Gero & Milovanovic, 2020; Hay et al., 2017; Sun et al., 2014).

7.6.3 Capturing Performance

Throughout the study, we relied on four measures of performance: *Self-assessed Novelty, Self-assessed Usefulness, Satisfaction with Solution,* and *Resolution of Problem*.

The variance across the performance measures suggests that performance is a multi-faceted construct. A correlation analysis showed that the only significant correlation between the performance measures was between *Satisfaction with Solution* and *Self-assessed Novelty* (Pearson's $r = 0.565$, $p < .001$) and *Satisfaction with Solution* and *Self-assessed Usefulness* (Pearson's $r = 0.480$, $p < .001$). This suggests that both the assessed novelty and usefulness influence the level of satisfaction with the solution and, thus, potentially capture dimensions of satisfaction. The lack of correlation between *Self-assessed Novelty* and *Self-assessed Usefulness* (Pearson's $r = 0.180$, $p = 0.241$) suggests they are independent of one another, as also argued by Pichot et al. (2022) in relation to measuring creativity. The fact that the self-assessed measures do not align with Hypothesis 3 and are not correlated with the rater-assessed measure *Resolution of Problem* could also suggest that the self-assessed measures do not capture actual performance. Even if capturing aspects of performance, the self-assessed measures might be influenced by how the participants experienced the intervention, affecting how they assess their performance, as suggested by Daalhuizen et al. (2014). While the influence of method usage on the experience of performance is interesting in its own right, it raises the question of whether performance can be captured by a self-assessed measure.

The inclusion of the self-assessed measures reflects the overall challenge of finding appropriate measures for capturing performance and quality of output. Measures like the *Product Creativity Measurement Instrument* (PCMI), measuring '...the subjective judgment of a product to exhibit novelty and appropriateness that elicits arousal and pleasure and is compatible with the judge's preferences' (Horn & Salvendy, 2009, p. 398), were considered but turned out not to be suited for the assessment of early-stage concepts and the brief written descriptions on which they needed to be assessed. Other performance measures often used in relation to idea generation, like the quantity of generated concepts, were rejected due to the difference in the underlying method goals and procedures, with, for example, the *morphological analysis* facilitating the exponential generation of ideas. This indicates why it can be a challenge to study fundamentally different methods, prompting different strategies for achieving the goals, even if the overall goals are similar, as in the case of this study. Some measures might favour some design strategies and bias against others.

In the end, we followed an approach similar to Sun et al. (2014) to measure what they refer to as *quality,* but we have called *Resolution of Problem*. However, this approach requires the development of new tailor-made items based on the design brief, entailing time-consuming refinements to ensure inter-rater reliability. The relatively low inter-rater reliability for the *Resolution of Problem* ($\alpha = 0.713$) achieved within the timeframe of this study highlights the challenges of such an approach. Furthermore, it only measures a narrow aspect of the quality of the concept related to the resolution of the problem—hence the name—ignoring others like desirability, practicality, feasibility, and sustainability. While it might not be possible to develop a general measure to capture design performance, this study suggests that design research could benefit from the development of better and more robust measures of performance.

7.6.4 Future Research

As shown by the shortcomings of this pilot study, both the phenomenon of method usage and the constructs of performance, cognitive load, and cognitive efficiency are complex. The above discussion makes several suggestions for improving the specific study design and research into the relationship between method usage and cognitive load, pointing a way forward for future research.

Besides the improvements suggested for this study, the complexity and the potential confounding variables could be reduced by identifying specific mechanisms embedded in methods and investigating them in isolation, e.g., using an A/B-testing setup. This would require further research into the manifestation of design methods and their building block to identify the mechanisms through which they prompt behaviours and actions. Such a strain research should ideally be accompanied by research testing design methods in less controlled environments as well. For example, investigating how the interaction of multiple design methods influences cognitive efficiency throughout a design process or how group dynamics and collaboration affect cognitive efficiency. By addressing these areas, future studies could contribute to developing more precise and effective design methods tailored to various user needs and settings. Furthermore, it would provide crucial insight for theory-building around method usage.

7.7 Conclusion

In conclusion, this pilot study examined the cognitive efficiency of systematic and heuristic design methods by analysing performance measures and cognitive load. The findings present an unclear picture of the influence of method usage on cognitive efficiency. *Cognitive load* did not, as expected, differ significantly across conditions, influencing cognitive efficiency in unpredicted ways. Cutting across it all, the control group generally outperformed the two groups using prescribed methods, indicating that the use of the method did not aid the participants. However, the lack of statistical significance and the low effect sizes warrant caution when interpreting the results. More comprehensive research is needed to refine our theoretical understanding and fully understand the interplay between using design methods and cognitive load. Measurement limitations regarding precision and sensitivity highlight the need for further refinement of the study design and the instrument used. Addressing these limitations in future studies will be essential to improving the effectiveness of design methodologies and their application in real-world settings.

8 Discussion

Although design methods have been crucial in the development of design research and new methods continuously emerge, our understanding of how they work and what determines their performance is limited. This dissertation set out to bridge this gap by investigating the phenomenon of method usage in design by focusing on the method users and their interaction with design methods, guided by the overarching research question:

How does the interaction between method and method user influence the user and the usage of methods in design?

Addressing this question, the constructs of *design mindset* and *cognitive load* have served as lenses for framing the method users and investigating the interaction between them and design methods. *Design mindset* emphasises the beliefs and values that guide a method user's approach, while the *cognitive load* lets us zoom in on the mental demands and *cognitive efficiency* associated with using design methods.

The following sections begin by discussing the key contributions of the research before expanding the conceptual work by integrating the constructs of *design mindset* and *cognitive load* within a broader framework of cognitive processing and method usage. Finally, the discussion addresses the implications for practice, acknowledges the limitations, and highlights opportunities for future research.

8.1 Inquiry I: Design Mindset

The method user—specifically their personality traits and *design mindset*—are at the heart of Inquiry I. Article I (Chapter 4) defines the construct of *design mindset*, operationalises it as an instrument for measuring it, and explores the relationship with the three personality traits: *self-efficacy, ambiguity tolerance*, and *sensation-seeking*. The development of the *Design Mindset Inventory* (*D-Mindset0.1*) helps concretise the abstract concept of *design mindset* and enables quantitative and statistical testing of its key components, relationships, and impact on method usage and design performance. Thus, the article takes a crucial first step in solidifying this core aspect of the phenomenon of method usage and provides a crucial tool for further theory-building.

The idea of a *design mindset* builds on the idea of a *method mindset*—the necessary practice knowledge, beliefs, and values to implement a method—expanding it to broadly cover the core values and beliefs associated with effective design practices. The core idea is that effective method usage and design practice require an alignment between the mindset of the designer and the activities they engage in. For example, if a method is built around being iterative, the designer should believe in the value of working iteratively (at least while using the method). Such alignment is crucial for the designer to recognise the affordance of a method and to act in alignment with it.

By also connecting the *design mindset* with the more generic personality traits, Article I paints a fuller picture of the method user and the complex interactions within their mind enabling them to be effective in design situations. It highlights the strong relationship between *design mindset* and the personality traits: *ambiguity tolerance* and *self-efficacy*. Both positively influence the *design mindset*-subconstructs *Conversation with the Situation* and *Co-Evolution of Problem-Solution*. *Ambiguity tolerance*, furthermore, influences the subconstruct *Iteration* positively. The relationship with *sensation-seeking* is less straightforward. It is positively related to the subconstruct *Imagination* and negatively to the subconstruct *Iteration* but has no significant relationship with the overall construct of *design mindset*. These relationships illustrate how different personality traits shape designers' mindsets and how they value certain aspects of design practice. Thus, Article I indicates that effective method usage requires more than just a fit between the design-related values and beliefs of the *design mindset* but likely also a fit with the deeper-rooted personality traits of the designer. Moreover, the results also suggest that *design mindset* is related to design training and experience, showing that participants engaged in design education have a significantly higher *design mindset* than participants with other educational backgrounds. As such, the article helps us gain a deeper understanding of the method user, the core component of *design mindset*, and how it is related to multiple aspects of the user's character.

Article II (Chapter 5) expands on Article I by investigating how *design mindset* is developed through method usage and how both the personality traits and initial *design mindset* scores moderate the development. By framing method usage as a way to develop *design mindset* and practice, Article II provides insight into a secondary function of design methods as tools for teaching/learning. In doing so, it provides a conceptual framework for understanding learning through method usage. While the primary function of method usage might not be to learn, it is nonetheless a central feature, as also indicated by its explicit inclusion in Daalhuizen et al.'s (2019) definition of design methods (see Section 2.2.1). Figure 5-2 places method usage in relation to Kolb's (2015) Learning Cycle, indicating how *design mindset* and expertise are built upon concrete experiences and reflection in and on action. While Article II focuses on the role of this process in developing *design mindset*, the framework also provides insights into the mental processing going on when using a method and how this process forms the actions of the method user. The conceptualisation of experiences prompts new actions to test if the conceptualisation aligns with the real world and if it improves the control of the design situation (see Kolb, 2015). As such, this framework helps open up a central aspect of Daalhuizen and Cash's (2021) model of method usage (Figure 2-4), providing insight into the mental processing of method users while using design methods.

Article II tests the underlying assumption that using methods influences the method users' *design mindset*. The results support this assumption, showing that method usage, as implemented through *Method Teaching*, generally increases *design mindset*, thus connecting method usage and *design mindset*. The effectiveness of method usage as a teaching tool is shown to be moderated by the preintervention level of *design mindset* and the personality traits. The preintervention level of *design mindset* and *Sensation-seeking* have a negative influence on the development of *design mindset* through method usage. Conversely, *Ambiguity tolerance* and *Self-efficacy* are found to have a positive influence on the development, as it also had on *design mindset*. Supporting the central role of the method user within the phenomenon of method usage, the results also show that the individual's personality traits play a larger role in determining the effectiveness of *Method Teaching* and the internalisation of design values than the contextual factors, like gender composition or level of *design mindset* in the group. This indicates that method users might be able to derive appropriate design values through the reflective practice of method usage despite variation in the implementation of the method, perhaps even from failed attempts to use a method. This aligns with the general idea of Kolb's (2015) Learning Cycle, where it is the individual's experience of a situation and reflection in and on this that drives the learning process.

Together, the two articles of Inquiry I provide crucial insights into the phenomenon of method usage in design. By defining the construct of *design mindset* and investigating some of its key relationships, the two articles identify core components of the phenomenon. The articles help to operationalise the idea of the method user, highlighting that the method user is more than just their design-related mindset and that more generic personality traits also influence their perspective on design practice. While this inquiry focuses more on the method user than the actual method usage, it provides a foundation for further investigation of the role of the method user within the phenomenon. Moving forward, the construct of the method user must be further unpacked to truly capture the multifaceted role they play in shaping not only the effectiveness of methods but the broader practice of design itself.

8.2 Inquiry II: Cognitive Load and Efficiency

Like Inquiry I, Inquiry II explores the phenomenon of method usage through the perspective of the method user. However, it shifts the focus from *design mindset* and its development to method usage and how it influences *cognitive load*. In doing so, Inquiry II adds an additional dimension to our understanding of the method user and their interaction with design methods, opening a new avenue for investigating the phenomenon.

The inquiry into the role of cognitive load in design emerged through an exploration of the cognitive science literature on problem-solving and creativity. *Cognitive load* emerged as a promising construct for explaining some core behavioural peculiarities of designers, e.g. their tendency to approach even well-defined problems as if they were wicked. Article III explores this tendency through the lens of cognitive load. This perspective positions design and method usage in relation to existing cognitive load research, outlining how designers utilise framing and reframing to expand the design space while keeping the complexity of the design task within the scope of their cognitive capability, thus avoiding cognitive overload while increasing creative potential. In doing so, Article III explores the potential explanatory power of the lens of cognitive load concerning design and method usage.

The article also highlights that the tendency to expand the design space to increase creative potential differentiates method usage in design from, e.g., the domain of learning where cognitive load theory is rooted. Where Cognitive Load Theory is predominantly focused on reducing ineffective or extraneous cognitive load (Sweller et al., 2019), effective design methods also need to help the method user efficiently manage and process information to allow for the expansion of the design space and its creative potential, i.e., increasing the cognitive load of the method user. This adds nuances to Cognitive Load Theory, as well as provides a crucial perspective for investigating the cognitive processes of design processes and activities.

Using Article III as its theoretical foundation, Article IV presents a pilot study investigating the ability of systematic versus heuristic design methods to facilitate cognitive efficiency. By combining *cognitive load* and performance, *cognitive efficiency* lets us investigate how designers perform in relation to the mental effort put into solving the design task.

While the results of Article IV were inconclusive due to a lack of statistical significance and small effect sizes, they suggest that neither the systematic nor the heuristic methods studied improved method users' performance, *cognitive load*, or *cognitive efficiency*. Generally, the control group outperformed both, either suggesting that the participants in the control group already had internalised design strategies comparable to those prompted by the methods, that methods usage increased *cognitive load* considerably without increasing performance, or that the study design and measures did not capture the *effective cognitive load*—the cognitive load needed to solve the task using the methods—but rather the cognitive effort expended, including any reinvested cognitive resources.

Despite the inconclusive result, Article IV showed how the framework of cognitive load enabled us to make predictions regarding cognitive load and efficiency and at least see trends aligning with these predictions. However, it also highlights the complexity of the construct of *cognitive load* and our limited understanding of it in relation to method usage, underscoring the challenges of measuring cognitive load in design, where the scope and complexity of a task depend on the problem framing. This calls for further theory-building related to design method, method usage, and how designers manage *cognitive load*.

The greatest advantage of *cognitive load* is that it captures many of the core variables of method usage. First of all, it is strongly related to experience, with training being the main way to reduce *cognitive load* (Chandler, 1993; Paas & Van Merriënboer, 1994; Sweller et al., 2019). *Cognitive load* has also been shown to be influenced by how information is presented (Hancock et al., 2021; Sweller et al., 2019), relating it to the manifestation of design methods (see Section 2.2.2). Likewise, situational factors like task novelty, time pressure, and reward systems relying on punishment are associated with high cognitive load (Paas & Van Merriënboer, 1994). Contextual factors such as extreme temperatures, noise, and other distractions can also increase *cognitive load* (Hancock et al., 2021; Paas & Van Merriënboer, 1994), and so too can the added coordination of working in teams (Sweller et al., 2019). As such, *cognitive load* captures both individual and contextual factors into one measure of how the design situations are experienced by the designer, giving us a way to assess how designers are impacted by a design situation and how this, in turn, influences their behaviours, e.g., how they interact with design methods.

However, as the inconclusive results of Article IV reveal, the complexity of *cognitive load* as a measure also makes it challenging to isolate effects and interpret the results in relation to design tasks. The complexity can obscure the actual *cognitive load* associated with using a design method. For example, if the similarity in cognitive load across the conditions is the result of the participants reinvesting any cognitive resources freed up by the methods. In highlighting the shortcomings of the study design, Article IV functions as an inquiry into the theoretical framing of the relationship between method usage and *cognitive load* and *efficiency*. The study shows that more work is needed to understand the relationship between cognitive load and method usage, both to enable research into this relationship and, more importantly, to understand the role of design methods in managing cognitive load.

In sum, Inquiry II expands our understanding of method usage and the method users by establishing a connection to *cognitive load* and *cognitive efficiency*. Together, the two articles underscore the importance of cognitive load in managing the demands of design tasks and adapting design methods effectively. They also demonstrate the need for continued research into the relationship between cognitive load and method usage to support both theoretical advancements and practical improvements in method development, teaching, and evaluation.

8.3 The Phenomenon of Method Usage

Combined, the two inquiries have contributed to our understanding of the phenomenon of method usage in design, highlighting the pivotal role of the method user in method usage and in adapting and applying design methods. Inquiry I mainly adds to our understanding of the method user and the development of *design mindset*, and Inquiry II adds a new perspective for understanding method usage based on *cognitive load*. By introducing the construct of *design mindset* and presenting new conceptual frameworks concerning both *method teaching* and *cognitive load*, the two inquiries provide new perspectives on the dynamic relationship between methods and users, laying the groundwork for future research and theory-building. To tie the two inquiries together, the following sections engage in a conceptual mapping of the relationship between *design mindset* and *cognitive load*, drawing on Dual-Process Theory to anchor the relationship in cognitive processing. As such, this section goes beyond a discussion of the results and synthesises the insights generated throughout the PhD project into a shared theoretical framework.

8.3.1 Cognitive Processing

Considering the construct of *cognitive efficiency*, it is worth considering method usage in terms of *cognitive load* and performance. As presented in Article III, there is a need to strike the right balance between cognitive effort and performance. In doing so, it is necessary to distinguish between when an increase in *cognitive load* is beneficial and when it is not. Cutting across the two inquiries, this furthermore requires a distinction between design methods as a learning tool and a design tool or, in broader terms learning and performance (see Balsam, 2014). Ideally, cognitive resources should be spent on the design activities prompted by the method. That is to say, the design activities that contribute directly to the resolution of the design problem, be it through, e.g., the exploration of the design space, idea generation, or experimenting. Resources spent on choosing, adapting, and applying a method do not necessarily benefit the achievement of the design goal, which is why Article III suggests that method usage should be considered a secondary task. In so far as the method usage does not increase the method user's *cognitive efficiency*, the application of a method adds to the *ineffective load* of the designer, drawing away cognitive resources that could otherwise be used on the design problem (Sweller, 1988; Sweller et al., 2019). Similarly, cognitive resources allocated to learning to use a method draw resources away from both the application of methods as well as the design problem, potentially resulting in inappropriate method usage and poor performance. As a result, to achieve *cognitive efficiency*, it is beneficial to minimise the cognitive resources taken up by method usage; ideally to the point where the design method has been internalised, and the design activities have become an intuitive response embedded in the designer's practice. Training is crucial in this process of moving the cognitive processing from the resource-intensive System 2 to the intuitive System 1 (Chandler, 1993; Kalyuga, 2009; Paas & Van Merriënboer, 1994; Stanovich, 2009) by automating both the method usage and even the design activities, which might justify the added cognitive load induced by the learning process.

However, achieving cognitive efficiency is not just about reducing *cognitive load*. To ensure quality performance, it is not irrelevant which cognitive processes are automated. In terms of method usage, we want to minimise the cognitive resources spent on method usage, that is, the resources spent by the algorithmic mind to apply and follow a method. The algorithmic mind is associated with the implementation of rules and procedures (Stanovich, 2009) and, thus, also the application of design methods (Daalhuizen & Hjartarson, 2022). While the algorithmic mind is necessary for upholding core functions of System 2 (Stanovich, 2009), the resources allocated to consciously following a method should ideally be so ingrained as to be intuitive, thus minimising the need for algorithmic thinking. If the design situation is familiar enough, the intuitive processing might be sufficient to ensure good design performance (Kahneman & Klein, 2009). However, as already established, design situations are seldom stable. Consequently, the applications of design activities, be it as internalised practices or through method usage, require the critical thinking and consideration of the reflective mind (see Kahneman & Klein, 2009). Similarly, even if the algorithmic mind has been engaged to follow a method systematically, it is not a guarantee for success. Like the intuitive processing might be sufficient if everything aligns with the approach, the algorithmic mind can only ensure good performance under 'optimal' conditions where there is a clear and logical connection between the design problem and the solution (see Stanovich, 2009). Without the reflective mind, System 2 cannot adjust the approach when it no longer fits the context of use or supports the achievement of the design goal. In other words, while the algorithmic process of following a method or doing design activities can be automated to reduce *cognitive load*, the reflective processes of assessing the affordance of a method and exploring the design space—as well as the necessary algorithmic processes to do so—should not be. In this light, method usage should ensure that the reflective mind goes in and overrides both the intuitive applications of design activities and the algorithmic mind to ensure the reflection necessary for the appropriate selection and application of methods, as well as the reflection on the design space, the design problem, and the solution. Even so, to ensure *cognitive efficiency*, the designer should revert back to the default mode of System 1 when the process is back on track.

In distinguishing between the role of the algorithmic and the reflective mind in relation to method usage, we can identify some crucial benefits of method usage and how it supports the achievement of design goals and performance. While aiming to minimise the resources allocated to the algorithmic mind for the application of methods to the point that actual method usage is no longer necessary, method usage can still play a crucial role in prompting reflective thinking. First of all, the knowledge related to the appropriate application of a method functions as a frame of reference, both prompting and anchoring reflections on the appropriateness of the specific sequence of design activities. Similarly, methods, both as physical manifestations or mental representations, should prompt productive reflection related to the design space, the design problem, and potential solutions. In fact, design methods' ability to do the latter is paramount for their ability to ensure design performance. Moreover, method usage might also play a crucial role in coordinating design activities in a team (Daalhuizen & Hjartarson, 2022).

One way design methods can prompt reflection is by making up for *mindware gaps*. Mindware can be thought of as cognitive software, including procedures, strategies, and mindset, on which the analytical System 2 relies to overwrite System 1 (Daalhuizen & Hjartarson, 2022; Stanovich, 2009). Without the necessary mindware, a method user would be unable to assess the appropriateness of a method or identify any needs for adjustment in its usage, leading to the type of cognitive errors Stanovich (2009) refers to as *mindware gaps*. That is, a failure to prompt reflection on the application of the method, due to a lack of insights into what methods are appropriate and how they should function. In lieu of experience or in novel situations, design methods can provide information about the relationship between sequences of design activities, the goal the method user is trying to achieve, and other factors that determine the appropriateness of the design activities in the specific design situation (see Daalhuizen & Cash, 2021). This ties into the important role of method content and the need for methods to contain the necessary information for prompting reflection on *method goal, method procedure, method framing, method rationale,* and *method mindset* (see Daalhuizen & Cash, 2021). Similarly, methods can also help bridge mindware gaps in relation to the broader conception of the design space and the design problem. By directing focus to specific elements of the design situation that otherwise might have been overlooked or ignored (see Daalhuizen, 2014; Dalsgaard, 2017) method usage can prompt reflections that otherwise would not have occurred, thus helping reduce bias, blind spots, and oversights.

More generally, even if a designer has the appropriate mindware, deliberate method usage might limit the risk of *cognitive misers,* where the method user defaults to System 1 thinking or fails to override the System 1 processing (see Stanovich, 2009). That is to say, by intentionally engaging System 2, method usage or even the deliberate application of internalised design activities might ensure critical reflections on both the design activities and the problem and solution space that an intuitive use would not. This goes beyond the ability of method usage to mitigate mindware problems and into the ability of the design method to facilitate the exploration of the design space. Method usage becomes a means to ensure the deliberate exploration of the design space, potentially increasing the creative potential, the quality of the design solution and, thus, the performance of the method user.

Considering how method usage mitigates mindware gaps and prompts critical reflection on aspects of the design space that might otherwise be overlooked, it is clear how method usage can mitigate, among other things, risk, oversights, and errors and alignment with industry and safety standards; all benefits associated with method usage (see Cross, 2008; Curry, 2014; Hjartarson & Daalhuizen, 2021; Jagtap et al., 2014; Lawson & Dorst, 2009; Newstetter, 1998). Furthermore, it details how design methods can stand in for practice knowledge and expertise in lieu of training, as suggested by Sweller (2023). However, when it comes to the resolution of the design problem, this function of method usage also points toward the importance of the fit between the method and the design situation and why specialised design methods can become problematic when transferred to new design situations. If the method prompts reflections on elements not crucial for the specific design situation, it could overemphasise optimisation in a situation where creativity is more appropriate or vice versa, the method usage diverts cognitive resources away from the actual resolution of the design problem. Conversely, it also shows why specialised methods might be necessary in situations where there is little room for error or specific aspects of a design situation need to be deliberately considered and reflected upon.

Method usage might also play a crucial role in mitigating the effect of *contaminated mindware*. Contaminated mindware relates to misaligned or faulty knowledge structures and beliefs, leading to erroneous conclusions or inappropriate, even counterproductive decisions or behaviours (Daalhuizen & Hjartarson, 2022; Stanovich, 2009). In using methods, inappropriate practices internalised by the method user can potentially be overridden, ensuring more appropriate responses to a situation and its needs. Furthermore, in prompting reflection on practice, method usage can aid the method user in identifying and adjusting contaminated mindware. Conversely, mindware can also be contaminated by inappropriate method usage or methods prompting inappropriate practices. Due to the general tendency of our brain to default to the least cognitive taxing process (Stanovich, 2009), designers might default to familiar design methods or activities without ever evaluating their effectiveness, resulting in inappropriate method usage and substandard mindware. This highlights both the importance of reflecting on the application of a method to ensure appropriate use and the importance of design methods aligning with good practices. This also points towards the importance of validation and testing of design methods to avoid the cultivation of contaminated mindware, as highlighted by Daalhuizen and Hjartarson (2022).

The above discussion has highlighted the need to distinguish between the cognitive resources allocated to applying a method and those allocated to the design activities it prompts. Method usage is not a goal in and of itself, and by distinguishing between cognitive resources needed to apply a method and those used on the design activities it prompts, the discussion provides a crucial distinction for understanding both the role of method usage in the design process and in the development of design practices and expertise. Method usage, in terms of ensuring effective and appropriate design activities, is primarily in service of the algorithmic mind and the continuous improvement of the method user's design practice. At the same time, design methods might support the reflective mind, both in relation to reflection on practice and, more importantly, by ensuring deliberate and more extensive reflections on the design space and potential solutions.

Outlining the cognitive processing related to method usage and how methods facilitate reflections adds nuances to the model of *Method Teaching* (Figure 5-2) presented in Article II. The role of method usage in filling in gaps in the mindware, prompting reflections, and adjusting for contaminated mindware highlights how design methods facilitate learning. In cultivating effective design strategies, both in terms of design activities and the underlying cognitive processes like information processing, method usage ensures the necessary mindware for the algorithmic mind to become more cognitively efficient when designing, ensuring that when System 2 takes over from System 1, it does so in the most efficient way possible. Moreover, the model of *Method Teaching* (Figure 5-2) helps explain how reflections prompted by method usage are translated into actions. Drawing on Kolb's (2015) Learning Cycle, reflections help conceptualise experiences into an understanding of a situation, which is then tested in the real world through actions aligning with this understanding. Consequently, by outlining how method usage helps prompt reflection, this dissertation adds to the discussion of how cognitive processes support design activities (see, e.g., Cash & Kreye, 2017, 2018), a process put at the centre of Daalhuizen and Cash's (2021) model of method usage (Figure 2-4).

8.3.2 Design Mindset and Cognitive Efficiency

The above discussion provides a foundation for framing *design mindset* in relation to the cognitive processing of method usage and tying it to *cognitive efficiency*. As part of designers' mindware, *design mindset* plays a crucial role in ensuring the effective processing of the algorithmic mind and enabling productive reflection in relation to the application of a method. An alignment between the method users' beliefs and values and the underlying ideas of the method should make it easier for the method user to process and understand the method content and overcome deficiencies or conflicts in the information, resulting in the method requiring fewer cognitive resources to be used (see Daalhuizen & Cash, 2021). Consequently, having a mindset that aligns with effective design practices should allow the method user to identify the affordance of a method, make good method choices, and efficiently adjust to any shortcomings or unique requirements of the design situation.

In this light, the method-mindset fit, highlighted as crucial for effective method usage (Andreasen, 2003; Daalhuizen & Cash, 2021), influences method usage in two distinct ways. Firstly, in reverse of methods' ability to make up for missing mindware discussed above, *design mindset* aligning with a method should allow a method user to fill in gaps in the method content, prompting the necessary reflection to ensure appropriate and effective method usage, despite shortcomings of the method. Secondly, a good method-mindset fit is likely to mean that the algorithmic minds already have appropriate mindware to implement the method efficiently, reducing the *cognitive load* needed to reflect on the method and 'install' the appropriate mindware. In theory, this should allow the method user to dedicate more cognitive resources to the reflections related to the exploration of the design space, increasing the creative potential and, ultimately, the quality of the design output. However, considering that reflections generally are triggered by encountering something unexpected (A. Y. Kolb & Kolb, 2022), with a good method-mindset fit also follows a risk of cognitive misers, where the method usage fails to prompt appropriate reflections. As already discussed, this might not be problematic under 'optimal' conditions, but in practice, it is likely to harm design performance. Failing to prompt reflection, the application of the method could potentially become substandard or even inappropriate to the detriment of both efficiency and design performance. Furthermore, this would indicate that the potential of the design method as a teaching tool is limited by increased method-mindset fit. Even so, a good method-mindset fit should increase the chances of appropriate and cognitively efficient method application, reducing the *cognitive load* experienced by the method user. This efficiency should furthermore allow the method user to invest more cognitive resources into the development of the design solution, thus increasing performance and ensuring high *cognitive efficiency*.

Without an alignment between *a design mindset* and a method, the method user might still be able to apply the method appropriately and achieve good design outcomes. However, it is likely to require significant cognitive effort and, consequently, take away cognitive resources that could have been dedicated to the development of the design solution. In design processes where the *cognitive load* is high, a poor method-mindset fit could result in *cognitive overload*, hindering efficient cognitive processing further and diminishing decision-making quality (see Paas & Van Merriënboer, 1994; Sweller, 1988, 2023).

The idea of method fit might be expanded beyond the fit between method and mindset. It seems likely that personality traits, like the ones found to influence *design mindset* in Inquiry I, would also influence a broader fit between method and method user. For example, a user with low *ambiguity tolerance* might find it more challenging to use divergent-focused methods aiming at opening up the design space or methods only providing general instructions rather the specific instructions. Following a similar logic as for method-mindset fit, this would likely also influence method usage and *cognitive efficiency*.

8.3.3 Good Design Methods and Performance

The above discussion highlights the central role of the method user in successful method usage. It also raises the question of what a good design method is and does. Taking the consequence of the framing of method usage as presented in this dissertation, it seems appropriate to reframe how we talk about method performance. The method-centric perspective, which has dominated design research (see Dorst, 2008), and is evident in relation to the systematic design methods and the importance put on following a method as prescribed, would suggest that it is the methods that ensure good performance. From this perspective, it is the *method user* that influences the effectiveness of a method. However, considering methods as mental tools, facilitating the cognitive processes and design activities of the user, it is not the design method that performs but rather the method user. In other words, it is the method that moderates the designer's performance. While a minor shift in framing, it put an emphasis on methods' ability to facilitate design activities efficiently, highlighting the potential impact of the manifestation of methods, as well as the method content and the method's fit with the method users' needs and abilities. From the *cognitive load* perspective, design methods should facilitate *cognitive efficiency* either by reducing the *cognitive load* of a designer, increasing performance, or some combination of the two. Compared with the method-centric perspective, this highlights the requirements to design methods, which should not only ensure quality outcomes but also the effectiveness of the method user in achieving them. This furthermore highlights the role of methods in developing efficient design practices and helps explain why designers tend to abandon the systematic application of methods as their expertise increases. For method usage to make sense from the *cognitive load* perspective, the added *cognitive efforts* needed to apply a method should be offset by increased *cognitive efficiency* when compared to the already internalised design practices of the designer. Consequently, the ability of design methods to facilitate performance efficiently becomes increasingly pertinent to their relevance as the abilities of the method user increase. This might help explain why more experienced designers primarily seek out new methods in novel or complex situations (Gericke et al., 2016; Schønheyder & Nordby, 2018). In such situations, the increased *cognitive load* of making sense of the situation might justify the additional cognitive effort of finding and applying a design method.

In relation to method development, this framing of method performance calls for a broader consideration of not only the design situation and the design activities needed to resolve it but also of the individual method user, their expertise, mindset, and personality traits. Considering the role of *design mindset* in method usage, as outlined above, it might be beneficial to consider how different users are supported by different methods, method manifestations, and method content. For some users, a detailed procedure might be necessary to facilitate the design activities, while others might only need a simple checklist or heuristic to prompt them. Recognising such differences when developing a design method could help ensure that methods are either explicit about who their target audience is or are manifested in such a way as to accommodate the diverse needs and cognitive profiles of individual users. It might even facilitate the creation of novel methods and design approaches, utilising alternative design activities to achieve similar method outputs as existing methods but accounting for individual *design mindsets* or preferences. For example, how would a version of the *morphological chart* function if it highlighted iteration rather than upfront analysis of sub-functions/problems? As such, this perspective on method performance not only highlights the usability of design methods but also encourages innovation in method development. By aligning methods more closely with the needs of method users, method developers can create tools that are more inclusive, flexible, and effective, ultimately contributing to better design outcomes, better mindware, and advancing design practice. That being said, such personalisation of methods might not be practically viable, but the concept presents an interesting academic exercise for investigating the interactions between design methods and method users and understanding how they facilitate design performance.

While on the subject of design performance, the above discussion on method usage, the underlying cognitive processes at play in the usage, and the role of *design mindset* has generally highlighted the role of practice knowledge related to the efficient and effective application of design methods and design activities. However, as touched upon several times, to ensure the quality of the design output, it is paramount that the reflection prompted by method usage goes beyond the application of the method and into the exploration of the design space. While practice knowledge is important in ensuring the efficient processing of the algorithmic mind, domain knowledge is likely crucial in ensuring *cognitive efficiency* when exploring the design space. Consequently, future research investigating *cognitive efficiency* in design should also expand on the role of domain knowledge and how it influences method usage.

8.4 Implications for Practice

As already indicated, the work presented in this dissertation, operationalising *design mindset*, developing conceptual frameworks, and describing the relationship between method usage and *cognitive load*, lays the groundwork for impacting design research, education, practice, and method development.

The operationalisation of constructs such as *design mindset* and integration of the *cognitive load* perspective opened new avenues for design research. They offer the foundation for researching the interaction between methods and method users in a more rigorous way. The provided frameworks serve as tools for bridging the gap between qualitative and quantitative approaches, enabling researchers to investigate the interaction between methods and method users in a more systematic and replicable manner. Moreover, this work encourages further refinement of research methodologies, guiding future inquiries into design activities by linking cognitive science with design-specific challenges.

Adding to the theoretical understanding of the phenomenon of method usage, this dissertation also provides important insight that could benefit further method development. Not only has it argued for the need for considering the manifestation of the method, the method content, as well as method-mindset fit to ensure the cognitive efficiency of the method user, by integrating Cognitive Load Theory, it has also taken the first steps towards evaluating design methods effectiveness as mental tools. This encourages the development of methods that are not only effective in achieving design goals but also flexible enough to accommodate the evolving needs of designers across varying levels of expertise and different design contexts. Ultimately, the dissertation paves the way for creating more efficient methods both in terms of creating quality design solutions and improving the skills and practices of method users.

Finally, the dissertation has emphasised the central role of method usage in fostering the development of a *design mindset*, an essential component of becoming an effective designer. By demonstrating how method teaching influences the development of *design mindset* and how individual and contextual factors shape this process, the dissertation provides educators with actionable insights to enhance the teaching of design methods and the development of *design mindset*. For instance, recognising the interplay between personality traits, cognitive capacities, and method usage allows for more personalised teaching approaches that align with the needs of diverse learners. The dissertation also underscores the importance of reflective practices during method usage, offering a basis for integrating reflective exercises into design curricula to reinforce the development of professional design behaviours. Furthermore, the cognitive load perspective contributes to educational strategies by encouraging the design of learning experiences that balance mental effort with skill acquisition. These contributions equip educators and practitioners with tools to nurture adaptive, reflective, and effective designers capable of tackling complex design challenges while fostering a lifelong engagement with method usage.

This combination of theoretical depth and practical relevance solidifies the dissertation's contribution to the discourse on design methods and their users. By advancing our understanding of method usage, it inspires future research, education, and practice to foster more inclusive, adaptive, and effective design approaches.

8.5 Limitations and Future Research

As an underexplored aspect of an underexplored phenomenon, the investigation of the interactions between design methods and method users has ventured into uncharted territory. To frame the phenomenon and define its components, it, therefore, has been necessary to integrate theories from outside the design field, operationalise constructs, and develop instruments to capture them. Consequently, the work presented in this dissertation has predominantly been conceptual in nature, resulting in less empirical support for the concepts and ideas presented than would have been ideal and were originally envisioned. This is also reflected in the preliminary nature of the empirical work. The *Design Mindset Inventory*, with its relatively low reliability (ω = 0.52) and indicated by referencing it as *D-Mindset0.1*, is only a preliminary instrument for capturing *design mindset*. Similarly, the study presented in Article IV is only a pilot study, and its results are only an indication of the potential relationship between *cognitive efficiency* and the use of systematic versus heuristic design methods. The inconclusive results highlight the challenges of capturing *cognitive load*, as well as measuring performance on design tasks, and in doing so, also display the still emerging understanding of *cognitive load* in relation to method usage in design.

The limited empirical support of the conceptual work has been further reinforced by the dual focus represented by the two strains of inquiry. The split between the two inquiries has limited the depth and scope of both and, as such, the dissertation. This could have been remedied somewhat if the relationship between the two constructs of *design mindset* and *cognitive load* had been investigated in the pilot study as originally intended. However, due to an error in the implementation of the *Design Mindset Inventory* in the data collection for Article IV (Chapter 7), we were unable to make connections between *design mindset,* performance on design tasks, and *cognitive efficiency*. Drawing this connection would have strengthened our understanding of the role of *design mindset* in method usage and should be pursued in future research. While the split between the two inquiries comes at the cost of depth and detail, it allows for a broader exploration of the phenomenon of method usage, providing complementary perspectives that contribute to a more holistic understanding of the interaction between design methods and method users.

The limited empirical support for the conceptual work presented in this dissertation underscores both its challenges and its opportunities. On the one hand, the limited empirical support minimises the immediate applicability of the findings, leaving key questions unanswered about the operational viability of the frameworks and constructs introduced. On the other hand, this also highlights the potential for future research to build upon the foundational work presented here.

One promising area for future research relates to the construct of *design mindset*. First of all, the *Design Mindset Inventory* calls for further refinement to improve reliability, ensure it captures the construct of a *design mindset*, that the theoretical underpinning of the subconstruct is supported, and improve the explanatory power of the inventory. More research is also needed to understand the relationship between *design mindset* and other constructs relevant to design. While we investigated its relationship to the three personality traits, *ambiguity tolerance, self-efficacy*, and *sensation-seeking*, the relationship to other constructs, e.g. the Big Five personality types, growth mindset, and instruments designed to measure creativity or design capabilities, would advance not only our understanding of *design mindset* but also help paint a more nuanced picture of designers and their characteristics. Such investigations could also include its relationship with educational background or specific design domains. However, it is perhaps most crucial to establish a correlation between *design mindset* and design performance to ensure the inventory actually captures the construct of *design mindset* as we have defined it. In establishing the relationship between *design mindset* and design performance, it is natural to also explore the *design mindset's* role in applying design methods efficiently and test the hypothesised importance of method-mindset fit. For example, does method-mindset fit allow designers to use an unfamiliar method even when the method content is poorly described, and does the fit reduce the *cognitive load* of the method user?

Research into *cognitive load* and *cognitive efficiency* in design has potential, especially in relation to the validation of design methods and exploration of their effectiveness under varied conditions. By leveraging these constructs, researchers can evaluate how different methods influence designers' mental effort, problem-solving capabilities, and overall performance. Cognitive Load Theory provides a framework for understanding the mental demands placed on designers during method usage, enabling researchers to assess whether methods facilitate or hinder *cognitive efficiency*. For example, future studies could employ A/B testing to compare different manifestations of a design method—such as a detailed procedural guide versus a heuristic checklist—to determine which format better supports cognitive efficiency and design performance. Such investigations would not only provide empirical validation for design methods but also inform their development, ensuring methods are tailored to reduce unnecessary *cognitive load* while maximising effectiveness. Researching design through the lens of *cognitive load* also has the potential to expand our understanding of design on a cognitive level. For example, *cognitive load* might play a similar role as uncertainty in guiding design behaviours, as described by Cash, Gonçalves, et al. (2023) in their *cognitive co-evolution model*. Establishing such relationships could support the conceptual framework presented in Article III.

Generally, the challenges encountered in capturing the method users' role in method usage emphasise the need for more sophisticated methodologies and tools capable of capturing the complexity of the phenomenon of method usage and the method users' role in it. By refining instruments like the *Design Mindset Inventory*, expanding the empirical investigation of *cognitive load*, and exploring method-mindset fit in varied contexts, future research can build on the theoretical contributions of this dissertation to expand the theory-building effort of understanding the phenomenon of method usage and the interaction between design methods and method users.

9 Conclusion

This dissertation set out to explore the phenomenon of method usage in design by examining the interaction between design methods and method users. It has investigated the development of *design mindset* through *method teaching* and usage and how using systematic or heuristic-based design methods influences *cognitive efficiency*. As such, it has placed the method user at the centre of this phenomenon, illuminating the dynamic nature of method usage, where the success of a method depends not only on the method but on how well it aligns with the user's mindset, traits, and cognitive capabilities.

By anchoring the research in existing theories from cognitive psychology, this dissertation integrates design research into a broader theoretical discourse, linking it with established principles of cognition, learning, and problem-solving to provide a multidisciplinary perspective on method usage. By applying Cognitive Load Theory to design, the research highlights the mental demands inherent in method usage and their implications for method effectiveness and efficiency. This perspective encourages future research to explore how different methods can be designed or adapted to minimise *cognitive load* while optimising performance and, thus, *cognitive efficiency*. It also positions cognitive efficiency as a promising metric for assessing method performance despite the challenges of measuring it in practice. As such, this dissertation opens new avenues for understanding the interaction between designers and design methods, providing a structured and quantifiable approach to evaluating method effectiveness. In doing so, it advances both theoretical development and the practical assessment of design methods, fostering a deeper understanding of the factors that influence successful design outcomes.

Furthermore, tying *design mindset* and *cognitive load* together, this dissertation has outlined the relationship between *design mindset*, method-mindset fit, and *cognitive efficiency*, providing crucial insights into the phenomenon of method usage and the interaction between methods and method users. As such, this dissertation contributes to the growing body of work and theory-building surrounding method usage, adding nuances to the current understanding of method usage and the reciprocal relationship between the method user and the methods they use. It has investigated gaps in the current understanding of the phenomenon and contributes the tools for future research to continue the exploration of these gaps and refine the principles underlying effective method usage. Adding to the theory-building efforts, this dissertation strengthens the design field's capacity to address increasingly complex and dynamic design challenges, laying the groundwork for developing better design methods, training, and, ultimately, ensuring better design practices.

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Appendix A

Pre-Intervention Questionnaire (Articles I and II)

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

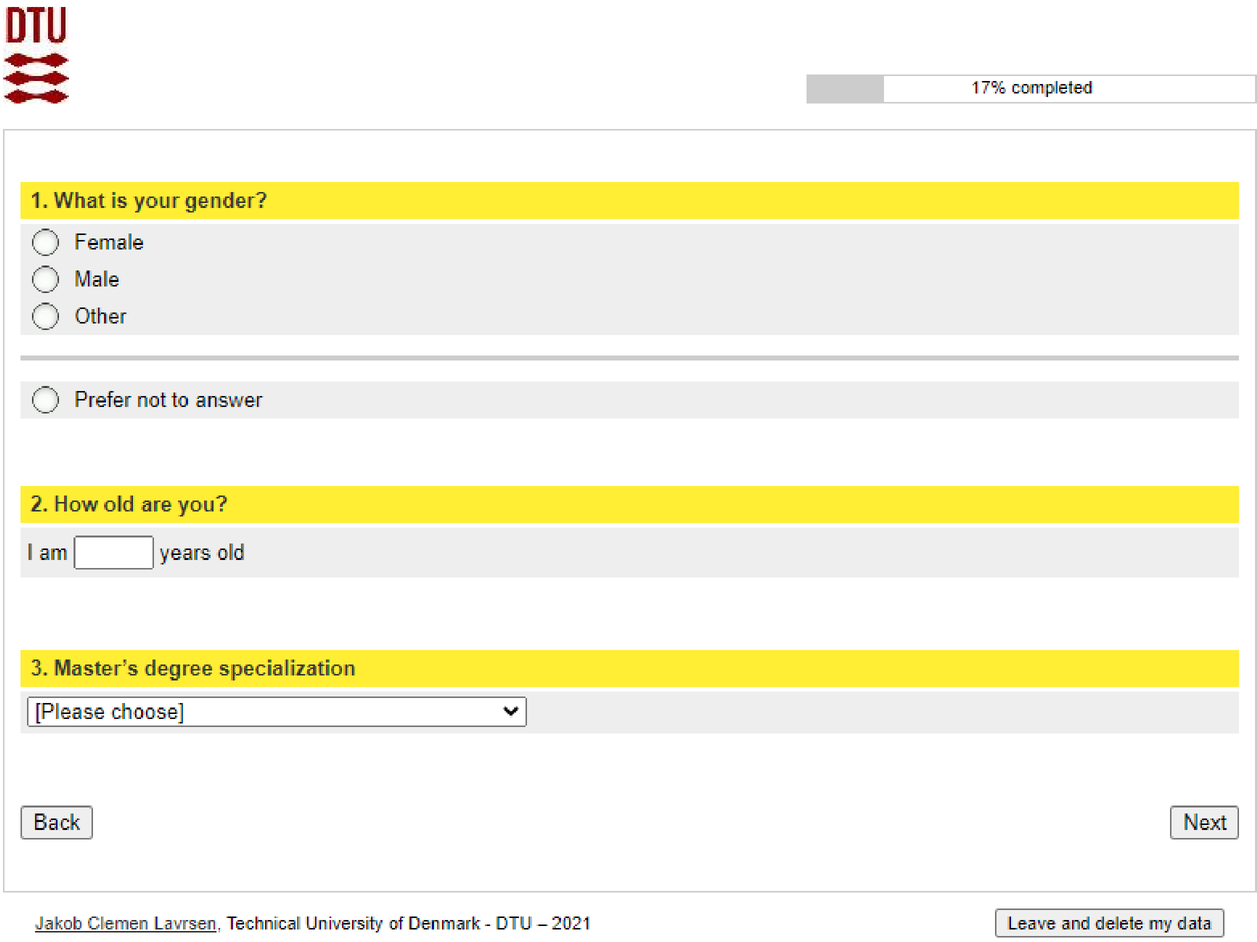
Please type in the six digits of your DTU student identification number. Your student ID will only be used for connecting data from the two questionnaires.

Student ID

Next

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

Leave and delete my data


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

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]

Back Next

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

DTU

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.	○	○	○	○	○	○	○

Appendix A

	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	○	○	○	○	○	○	○

	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.	○	○	○	○	○	○	○

Statement	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.	

Back Next

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

Leave and delete my data

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

Post-Intervention Questionnaire (Article II)

DTU

0% completed

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

DTU

50% completed

	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.	○	○	○	○	○	○	○

Appendix B

	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	○	○	○	○	○	○	○

	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.	○	○	○	○	○	○	○

Next

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

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 C

Proportions of Educational Backgrounds in the Sample (Article I)

Educational background	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
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

Appendix D

Proportions of Educational Backgrounds in the Sample (Article II)

Educational background	Counts	Total	Proportion (%)
Sustainable Energy	32	254	12.6
Architectural Engineering	27	254	10.6
Biotechnology	22	254	8.7
Civil Engineering	19	254	7.5
Chemical and Biochemical Engineering	18	254	7.1
Industrial Engineering and Management	18	254	7.1
Pharmaceutical Design and Engineering	14	254	5.5
Electrical Engineering	13	254	5.1
Computer Science and Engineering	12	254	4.7
Design and Innovation	9	254	3.5
Autonomous Systems	8	254	3.1
Earth and Space Physics and Engineering	8	254	3.1
Business Analytics	7	254	2.8
Mechanical Engineering	7	254	2.8
Transport and Logistics	7	254	2.8
Materials and Manufacturing Engineering	6	254	2.4
Bioinformatics and Systems Biology	5	254	2
Wind Energy	3	254	1.2
Others	3	254	1.2
Advanced Materials and Healthcare Engineering	2	254	0.8
Applied Chemistry	2	254	0.8
Engineering Acoustics	2	254	0.8
Environmental Engineering	2	254	0.8
Food Technology	2	254	0.8
Human-Centered Artificial Intelligence	2	254	0.8
Biomedical Engineering	1	254	0.4
Mathematical Modelling and Computation	1	254	0.4
Physics and Nanotechnology	1	254	0.4
Technology Entrepreneurship (cand.tech.)	1	254	0.4