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From theory to practice: a roadmap for applying dual-process theory in design cognition research

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ABSTRACT

Dual-process theory categorises cognition into two types of processing: Type 1 which is intuitive, autonomous processing, and Type 2 which is reflective processing that burdens limited executive cognitive resources (i.e. working memory). A recent call for increased theory-driven research in the field of design has led to a framing of dual-process theory as a foundation for design research. This research note presents a roadmap for future dual-process theory-driven design research outlining three main stages: defining dual-process theory constructs, determining research focus, and selecting research methods. Across these stages, we offer a conceptualisation of dual-process theory for design researchers, outlining the main concepts of the theory. We then present how a research study design must consider the nature of design problems (complex, ill-structured, ambiguous), designers, and the practice of design. Finally, we outline the main methods employed in dual-process theory research: behavioural, physiological, and self-report measures, suggesting ways to adapt such methods to design contexts. Ultimately, this work presents how dual-process theory may connect with theories of cognition often considered in design and offers a path forward for dual-process theory-driven design research.

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1. Introduction

Design cognition research – the study of a designer's mental processes while designing – has recently seen increasing engagement with dual-process theory (DPT). DPT was developed in cognitive psychology and categorises cognition into two types of processes: intuitive, autonomous processing (Type 1), and reflective processing that burdens limited executive cognitive resources (Type 2) (Neys 2018; Evans and Stanovich 2013). From theorising (Kannengiesser and Gero 2019) to observing design under experimental conditions (Gonçalves and Cash 2021), DPT is finding its footing within design cognition research as a theoretical lens.

The field of design research is facing increasing calls for theory-driven research and greater rigour (Cash 2018; Chakrabarti and Blessing 2014). Design cognition research lacks

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a common ontological foundation, consistent method use, and established research practice norms (Blessing and Chakrabarti 2009; Cash 2018; Hay et al. 2017; Levin and O'Donnell 1999). DPT, as a well-established theory with reliable methods, has the potential to address these limitations. Increased consistency in design cognition research would improve: accessibility to design research, knowledge transfer with adjacent fields (Hevner 2007), the ability to synthesise research, generalisability of conclusions, and work comparison (Hay, Cash, and McKilligan 2020).

The application of DPT in design cognition research has many potential benefits but introduces its own challenges. Adopting theories from adjacent fields may come with an incomplete understanding of the underlying principles, resulting in limitations (Blessing and Chakrabarti 2009). Additionally, staying updated on knowledge and theoretical developments is crucial when consulting unfamiliar disciplines. Dual-process theorists also propose different models of the theory, posing challenges in determining suitability for design research goals, synthesising research across models, and identifying relevant DPT debates for design. Furthermore, DPT understanding is hindered by the noise of critiques and clarifications scattered over decades of papers, which has resulted in a flawed, culturally perceived version of the theory (Evans 2012).

Despite challenges, DPT offers a potential new design research framework with the diversity of the theory offering flexibility. Design research may even aid in clarifying DPT debates and help drive the theory forward. Ultimately, integrating DPT into design cognition research has the potential to address current challenges, enhance consistency, provide established methods, and improve accessibility and knowledge transfer in design research.

2. Approach and definitions

Adapting DPT to design contexts requires careful consideration of semantics, such as the fragmentation of terminology in the use of *System 1* and *System 2* as an alternative to *Type 1* and *Type 2*. The 'system' terminology was popularised at the end of the twentieth century (Stanovich 1999) and continues to be used by certain authors (Neys 2018; Kahneman 2011). However, several DPT theorists favour 'types,' arguing that 'systems' implies that each processing type is generated by a single brain system rather than multiple brain systems – potentially contributing to DPT misconceptions (Evans 2011; Stanovich, West, and Toplak 2014). While both terms are still widely used, to avoid such misconceptions, this paper will use the terms Type 1 and Type 2.

Our work aims to translate DPT knowledge from cognitive psychology to our own field in an easily digestible roadmap while giving insight into the debates of the theory and minimising the potential research confusion from applying underdeveloped theory. In this paper, we present findings from a snowball literature review, a method for literature reviews that involves iteratively defining a set of papers and conducting forward and backwards citation searching to identify additional relevant papers (Wohlin 2014). This procedure was independently conducted by two researchers to ensure coverage of a greater number of works. After finalising a set of key papers on DPT in both the fields of cognitive psychology and design, we distil the core DPT constructs and relationships from the cognitive psychology literature, explore how these may be translated to a design context, and propose a roadmap for applying DPT to advance knowledge about the cognitive processes involved

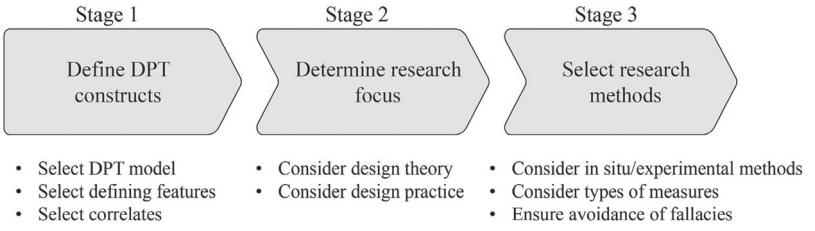

Figure 1. The main stages of the roadmap for DPT-driven design research.

in designing. This roadmap consists of three main stages, as summarised in Figure 1. In what follows, we detail important considerations in each stage for DPT-driven design research.

3. Stage 1 – Define DPT constructs

To achieve the desired rigour offered by a DPT framework in design research, it is essential to understand the foundational principles of the theory. In this stage, we outline the main components of the theory and discuss features and correlates of the theory for future research.

For centuries, theories that divide thought into two distinct categories of fast intuition and slow reflection have permeated writing and culture. This can be traced as far back as Aristotelian ideas dividing the mind (viewed as rational) from the body (viewed as the source of emotional thought) (Evans 2010). Prominent cognitive psychologists of the late twentieth century developed more refined ideas of the dual-processing nature of thought which are now held in wide academic regard (e.g. Wason and Evans (1974)) and have snowballed into a popular cultural concept (e.g. Kahneman (2011)). DPT divides cognition into *Type 1* intuitive, autonomous processing, and *Type 2* effortful, reflective processing that burdens executive cognitive resources (Neys 2018; Evans and Stanovich 2013).

3.1. Select which DPT model will frame the research

There are three main models of DPT – the default-interventionist model (also called the serial model), the parallel processing model, and the hybrid model. These have been summarised in Table 1, outlining the primary difference between the models (the order of processing) and definitions used by a sample of the most prominent authors of each model.

While there are commonalities between DPT models, the key difference is the order in which Type 1 and Type 2 processing occur. The dominant model in the field is the default-interventionist account, whereby Type 1 processing occurs automatically and provides an intuitive response that may subsequently be moderated by Type 2 processing (Evans 2018). While such accounts consider Type 2 processing to always be engaged, at least at a low level, the first role of Type 2 processing is to determine if the intuitive response is justified (Evans 2018). The parallel processing model differs in this, with both Type 1 and Type 2 processing operating simultaneously, generating competing responses (Trippas, Thompson, and Handley 2017). Here, the given response is dictated by the complexity of the

Table 1. Main DPT models and theorists' definitions.

	DPT Model					
Debate	Default-interventionist (serial)		Parallel processing		Hybrid model	
Order of processing	Type 1 processing provides an intuitive response than may be subsequently moderated by Type 2 processing		Type 1 and Type 2 processing occurs in parallel with both responses competing		Type 1 generates two types of responses: heuristic and logical. Type 2 may then moderate the response.	
Author	Evans (2019)	Kahneman (2011)	Handley & Trippas(2015)	Trippas, Thompson, and Handley (2017)	Neys (2018)	Pennycook, Fugelsang, and Koehler (2015)
Definition of Type 1 processing	Intuitive autonomous responses or judgements accompanied by a feeling of rightness	Automatic, quick, with little or no effort and no sense of voluntary control.	Quick, effortless, high capacity, and autonomous.	Autonomous	Fast, effortless	Autonomous and do not require working memory
Definition of Type 2 processing	Slow, reflective, and which engages working memory	Attentional allocation to effortful mental activities. Associated with subjective experience of agency, choice, and concentration.	Slow, effortful, low capacity, reliant upon working memory resources, and therefore slow	Requires working memory	Slow, effortful, burdens limited executive cognitive resources	Deliberative and require working memory

problem, with logical judgements superseding belief judgements in simpler cases (Trippas, Thompson, and Handley 2017). Alternatively, hybrid models (taking the middle ground between these models) propose that Type 1 processing provides two potential intuitive responses which may then be moderated by Type 2 processing (Neys 2018). These two responses are referred to as the logical intuitive response (founded in basic logic and probabilities) and the heuristic intuitive response (founded in associations) (Neys 2018). The hybrid model ultimately proposes that Type 1 processing can generate correct responses through both basic logic and biases (Neys 2018). Much of the debate between these models and the order of processing stems from studies showing that logical processing can be performed parallel to belief-based responding (Neys 2012; Handley, Newstead, and Trippas 2011; Trippas, Thompson, and Handley 2017). However, such studies use simple reasoning tasks for which Type 1 processing could automatically process the simple logic (i.e. Type 1 processing could produce both the logical and belief-based responses) (Evans 2019).

While such work poses questions for the order of processing, more research is needed to settle which model most accurately describes DPT phenomena. It is not necessary that the design cognition discipline pigeonholes itself into a single DPT model; however, it is necessary that those applying DPT in design provide a well-defined and contextualised overview of the selected DPT model and definitions of Type 1 and Type 2 processing.

3.2. Select the defining features and correlates of Type 1 and Type 2 processing

Dual-process theorists propose varying defining features of Type 1 and Type 2 processing (see Table 1). Certain features considered defining by some, are considered correlates by others (Evans and Stanovich 2013). Commonly considered correlate features of Type 1 and Type 2 processing are: fast and slow, conscious and nonconscious, and belief-based and normative, respectively. For example, fast processing is associated with Type 1 processing due to its automatic and intuitive nature, while slow processing is associated with Type 2 processing as more effortful and reflective thought. While this is often the case, there are exceptions (Evans 2011). Indeed, these tempting shorthands to roughly identify the processing types are considered fallacies of the theory (Evans 2012).

The speed fallacy, defining Type 1 and Type 2 as 'fast' and 'slow' processing, has featured in recent DPT-driven design research (e.g. Cash and Maier 2021; Gonçalves and Cash 2021; Kannengiesser and Gero 2019). Such tendencies may place limitations on the current conclusions of DPT design research. Additionally, drawing links between 'fast' design processes like concept generation, and 'slow' design processes like concept evaluation with Type 1 and Type 2 processing, respectively, is an intuitive assumption, but risks losing the nuance of both designing and DPT. The remaining fallacies are contextualised within design research in section 5.2.

While existing DPT-driven design research relying on such associated features may give broad insight into the workings of dual-processing in design, we must consider the conclusions of such work carefully. Distinguishing between defining features and correlates is crucial to ensure that design research can accurately capture dual-processing phenomena. Furthermore, ensuring that design researchers outline their DPT perspective will facilitate greater understanding and synthesis of future work.

4. Stage 2 – Determine research focus

Once a researcher has a comprehensive understanding of DPT and how to motivate their research in this theoretical foundation, they must define their research focus. Since this paper aims to present a roadmap for conducting DPT-driven *design* research, we now outline key considerations for applying DPT in *design* contexts.

4.1. Consider design theory

Design is often considered to be the act of solving complex and ill-structured problems (Jonassen 2000) that requires intentional action to achieve desirable outcomes (Nelson and Stolterman 2014). This perspective frames design as a structured process, with stages following the approximate pattern of problem finding, conceptual design, preliminary design, detailed design, and communication (Dym, Little, and Orwin 2014). Design extends beyond problem solving, considering real context and real people, and the subjective qualities of designers that may lead them to a unique approach (Daly et al. 2012). The study of the mental processes of designers has been termed design cognition, a discipline that acknowledges the necessity to contextualise research within the design process. Recent design cognition research has seen an increasing application of DPT in answering calls for theory-driven research (Cash 2018).

Preliminary research has begun framing DPT in a design context and includes a dual-process ideation model (Gonçalves and Cash 2021), an alignment of DPT with design ontology (Kannengiesser and Gero 2019), and contrasting design representation methods with a DPT lens (Cash and Maier 2021). Flus and Olechowski (2023) identify patterns of cognitive processes in design phases; for example, ideation involves rapid idea generation, a process likely dominated by Type 1, followed by periods of reflection and reframing characteristic of Type 2 reasoning (Gonçalves, Cardoso, and Badke-Schaub 2016). While such design research is in its early stages, what has emerged is the proposal of DPT to (1) elaborate on existing design research, (2) address gaps in existing design theory, and (3) support the impact of design research in other fields (Cash et al. 2019).

We see potential for DPT conceptualisations of many design processes, especially those that present a duality, such as Schön's (1983) reflection-in-action versus reflection-on-action and divergent versus convergent thinking (e.g. Cross (1999); Dorst (2011); Goldschmidt (2016)). Many of these tenets of design research, at the surface level, could be mapped as more intuitive vs reflective thought. Indeed, recent work focusing on these tenets of duality in design has referred to dual-process theory (e.g. Cash, Gonçalves, and Dorst 2023; Kelly and Gero 2021). Ties to DPT can provide a useful frame of reference to such work; however, caution should be taken to avoid direct comparisons that simplify DPT.

The field of design research currently lacks an overarching understanding of what it means to design according to DPT – a foundation of knowledge we argue is necessary for future DPT-driven design research. The act of designing is unique from other types of problem solving, as described by the phases of the design process; therefore, DPT-driven design research must account for design context. Engaging in DPT-driven design research requires researchers to consider the how both types of thinking may be active during design decisions at different phases of the design process.

4.2. Consider design practice

Design is highly dependent on the designer; therefore, the experimental design for design cognition research must consider characteristics of the designer and design practice. While there are many factors to be considered, we choose to discuss a designer's level of experience and design collaboration, both of which we see as highly central in design research.

4.2.1. Expertise

Contrasting experts and novices is a dominant research paradigm used to investigate design cognition, a trend likely to translate to future DPT design research. While limited research exists in other fields investigating expertise from a DPT approach, insights from diagnostic reasoning indicate that experts rely more on Type 1 thinking than novices in visual processing tasks (Warren et al. 2018). These findings may point towards the greater knowledge base of experts leading to a greater ease in associative processing (correlated with Type 1 thinking). Greater automation of processing may also enable experts to free up cognitive resources (e.g. working memory – see section 5.2.1.2) (Evans 2008), which can then be used in other design activities.

Experts and novices are also likely to use Type 1 and Type 2 processing differently. Novices may employ Type 2 processing in a slow and careful manner during the design process. Alternatively, experts, with a broader knowledge base, may work in a quick and casual manner using heuristics that have been learned to automaticity but still need to be applied explicitly (i.e. using Type 2 processing) (Evans 2011). Mathematical expertise research supports this idea; for example, Purcell, Wastell, and Sweller (2020) found that individuals with low experience engage in Type 1 thinking or ineffective Type 2 processing, those with intermediate experience engage in effective Type 2 processing, and high experience is associated with Type 1 processing. Consequently, both inexperienced and experienced designers may rely more on Type 1 processing and the correlation between expertise and type of processing is not perfect. However, the differences in how Type 1 and Type 2 processing are used as expertise grows could be an interesting avenue for DPT design research.

Different DPT models may motivate investigations into design expertise differently. For example, Evans (2019) 'Default-interventionist model' prompts some interesting connections through considering how expertise influences: (1) determining if an intuitive response is justified and (2) recalculating an unjustified response. Following this, design expertise is likely to play a crucial role in evaluating the justification of ideas, which aligns with research indicating that experts assess decisions before implementation (Ahmed, Wallace, and Blessing 2003). Novice designers, with limited knowledge, may struggle to recognise an unjustified intuitive response, reflecting the common novice 'trial and error' pattern (Lohmeyer, Meboldt, and Matthiesen 2013; Ahmed, Wallace, and Blessing 2003). Design expertise may also aid in the reformulation of unjustified responses, as experts have better knowledge of methods and design heuristics, while novices may face challenges in this aspect. Ultimately, understanding how Type 1 and Type 2 thinking evolves with expertise is a crucial avenue for future DPT design research.

4.2.2. Collaboration

It is rare for design to occur in isolation; in fact, there is increased interest in engaging in interdisciplinary collaboration (Klein 2014). While much existing design research has explored cognition in team settings (e.g. Stempfle and Badke-Schaub 2002; Wiltschnig, Christensen, and Ball 2013), few studies have used DPT to understand collaboration. This is likely because most DPT research considers individual cognition, while in design, many decisions are not made independently. Recent psychology research has explored group cognition from a DPT lens. Specifically, researchers have investigated the tendency of individuals to cooperate and overrule selfish behaviours. Humans are innately biased towards or against pro-social behaviour (Chen and Krajbich 2018); in other words, some people will be more intuitively inclined to cooperate than others. One study found that initial responses to a social dilemma favoured cooperation, suggesting cooperation is an intuitive response (Costa, Arantes, and Keating 2022). Such findings shed light on how people may collaborate according to DPT and call for more in-depth and experimental studies on collaboration according to dual-process theory.

Outside of DPT-driven research, we can turn to design cognition research to gain a deeper understanding of teamwork. There has been extensive research done on cognition during collaboration – revealing the ways in which teams share mental models (Mohammed, Ferzandi, and Hamilton 2010), and how knowledge can be distributed across the group rather than in individual brains (Clark and Chalmers 1998). It then follows that an individual may be involved in a decision, but the reasoning of the decision was shared between team members. In such cases, it would be complex to identify the type of cognitive process engaged and by whom. Thus, the distributed nature of design decision making must be considered.

Since teamwork is integral in design, the future of theory-driven design research must consider the collaborative nature of design decision making. We argue that while challenging, considering DPT in studies of collaborative design is possible. This research would have to consider how the team works together and the distributed nature of their cognition.

5. Stage 3 – Select research methods

The complexity of the design process requires a diverse range of research approaches, often incorporating methods from adjacent fields (Blessing and Chakrabarti 2009). Alongside design research methods, DPT research offers more established research methods for studying participant thinking and errors. However, applying methods from adjacent fields should be met with caution to ensure a comprehensive understanding of underlying principles.

In this stage, we discuss research methods in three steps: considering in-situ and experimental methods, considering types of research measures (discussing paradigms from cognitive psychology and design cognition research), and ensuring the avoidance of fallacies (common misconceptions about DPT). Due to the significance of context in design research, and to foster a better understanding of the practicalities of DPT design research, the fallacies (common misconceptions about DPT) and debates of DPT are discussed throughout the research methods.

5.1. In-situ and experimental DPT research methods

Design experiments can be conducted both in-situ, in industry or educational settings, and experimentally, in controlled laboratory environments. Design researchers often turn to in-situ data collection to capture a more authentic representation of design. However, such settings leave many variables uncontrolled limiting the ability to generalise conclusions. Additionally, we may need advances in framing DPT for design to maximise the effectiveness of traditional design cognition research methods (e.g. developing DPT coding schemes for protocol analysis). Methods used to study DPT in cognitive psychology are usually experimental, offering greater rigour and internal validity. However, these methods may struggle with the nature of design problems – complex, ill-structured, ambiguous, and with no determined solution path (Jonassen 2000). Therefore, future experimental design research must consider which cognitive processes can be assessed using well-established tests from cognitive psychology, and for which must we develop design specific psychometric tests. It is likely that a balance of both in-situ and experimental methods will be needed to test and validate DPT in design research.

5.2. Consider types of research measures

To guide the discussion of DPT research methods for design research, three types of measures will be discussed: behavioural, self-report, and physiological. This categorisation, taken from cognitive psychology (Cozby 2009; Hiscock 2003), has been recently applied to design cognition ontology (Lawrie, Hay, and Wodehouse 2023). Here, behavioural measures refer to direct observations of behaviour, self-report measures focus on participants' own descriptions of their cognition, and physiological measures assess bodily outputs (Cozby 2009; Hiscock 2003; Lawrie, Hay, and Wodehouse 2023). This classification also facilitates triangulation of research – a fundamental driver of theory building and testing (Cash 2018).

5.2.1. Behavioural measures of DPT

5.2.1.1. Heuristics and biases. Behavioural measures are the most dominant in DPT cognitive psychology research across the different models. Primarily centred around the concept of cognitive bias (originating in the heuristics and biases programme of Tversky and Kahneman (1974)), these measures almost exclusively use written tasks that either do, or do not, require Type 2 processing to provide the correct response.

Most of these written tasks induce belief bias: whereby when presented with an argument, people will find a conclusion acceptable if it aligns with their existing beliefs, regardless of its logical validity (Ball, Thompson, and Stupple 2018). That is, people tend to focus on preconsciously cued beliefs and maintain the resulting conclusion, without considering alternatives. Reasoning tasks exploiting belief-bias, by inducing a discrepancy between belief-based and logic-based responses (i.e. causing cognitive conflict (Evans 2007)), have been the archetypal case for identifying Type 2 processing and developing DPT (Evans 2008). The paradigmatic test illustrating this cognitive conflict involves syllogisms (deductive reasoning tasks), where participants are asked to assess logical validity (Evans 2008). An example syllogism from Handley and Trippas (2015) is:

All living things need water

Roses need water

Therefore, roses are living things

1. The conclusion is valid (incorrect)
2. The conclusion is invalid (correct)

Both the validity (if the conclusion is true following the premises) and the believability (if the conclusion aligns with the participant's beliefs) of such syllogisms can differ (Evans 2008). In the example above, the conclusion is invalid but believable (i.e. a belief-logic conflict).

Alongside syllogisms, researchers use deductive reasoning tasks intended to measure the tendency of a participant towards Type 2 processing to override an intuitive response (e.g. Pennycook 2018; Toplak, West, and Stanovich 2014). The most famous of which is the 'bat and ball problem' developed by Frederick (2005) as part of the Cognitive Reflection Test. The problem is as follows:

A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball.

How much does the ball cost? _____ cents

It is easy to see the intuitive answer to the question (10 cents), while it may take some reflection to determine the correct answer (5 cents). Such reasoning tasks, similar to syllogisms, induce an incorrect intuitive response, or 'lure', that conflicts with the correct response gained through Type 2 processing.

The Cognitive Reflection Test also measures a factor that could prove crucial to DPT design research – rational thinking disposition (sometimes referred to as cognitive style (Trippas et al. 2015)). That is, an individual's inherent tendency to rely differently on Type 1 or Type 2 processing (Trippas et al. 2015; Stanovich, West, and Toplak 2016). Investigating the rational thinking disposition of designers may be crucial to the development of tools and methodology to aid and cater to individual designer needs in the design process. The employment of Type 1 or Type 2 processing is also influenced by the context. An expert designer is far more likely to rely on Type 1 processing in many situations where a novice would respond with Type 2 due to processes learned to automaticity over time. Additionally, each phase of the design process may also be dominated by Type 1 or Type 2 responses.

Type 2 processing is also prone to biases, including the maintenance of 'the current mental model with insufficient consideration or evaluation of alternatives' (Evans 2018). This bias of Type 2 processing holds similarities to the often-discussed concept of fixation in design – an illogical adherence to a perceived set of limitations or ideas while designing (Jansson and Smith 1991). Following this, researching fixation through a DPT lens could provide interesting insight into design cognition. Ultimately, design researchers applying DPT must be aware that both Type 1 and Type 2 processing can generate belief-based and logical responses.

Often present in DPT discussion on bias is the idea that Type 1 generates fast and careless conclusions based on prior beliefs, while Type 2 processing leads to normatively correct answers from effortful reflection (referred to as the *normative fallacy*) (Evans 2018). However, intuitive answers can be correct through a fortunate guess, learned associations, or

a useful heuristic (Evans 2018). In design, intuition can generate good solutions honed through the accumulation of experience (Badke-schaub and Eris 2014).

Despite many nuances to be considered, we see much potential for heuristics – and – biases-based methods for studying DPT in design, particularly through reasoning tasks that elicit bias in participants within a design context. For example, does conflict between belief-based and logic-based reflections about a concept cause designers to make certain decisions, and does belief bias cause a designer to follow an intuitive concept direction without understanding the full complexity of the problem? One challenge here is that the bias central to these tasks may hold a different weight within design contexts than it does in the traditional reasoning tasks of cognitive psychology. This results from design operating through a satisficing nature (Simon 1972), whereby designers generate and develop their own solutions rather than assessing given alternatives. That is, there are incorrect or unsatisfactory design solutions, but there are multiple solutions to satisfy any given design problem, not a singular correct answer (Jonassen 2000). This contrasts with the absolute nature of DPT reasoning tasks. A key avenue for future DPT design research is determining how Type 1 and Type 2 biases influence design outputs.

5.2.1.2. Cognitive constraints. Another common DPT behavioural method involves applying cognitive constraints to influence the type of processing used in a study response. This is often done by loading the participants' working memory – an individual's capacity to temporarily store and manipulate information to support ongoing cognitive activities (Baddeley, Allen, and Hitch 2011; Logie, Camos, and Cowan 2021). Working memory is a defining feature of many definitions of Type 2 processing (see Table 1). Within the dual-process account, a loaded working memory should interfere with the participants' ability to engage Type 2 processing as these limited resources are already occupied by effortful cognitive tasks, such as counting aloud. Such experiments have indeed shown that Type 2 processing decreases as working memory load increases (Baddeley, Allen, and Hitch 2011). In other words, when participants have a loaded working memory, they rely more on Type 1 reasoning.

Correlational analysis has shown that regardless of differences in loading task content, these tasks seem to similarly affect the performance of the working memory (Wilhelm, Hildebrandt, and Oberauer 2013). That is, working memory capacity seems to exist independently of the task that requires its use, and this capacity varies between individuals (Cowan 2010; Wilhelm, Hildebrandt, and Oberauer 2013). Therefore, the impact of loading working memory on cognition would likely hold in design contexts. Possible applications of this method may involve asking participants to count aloud while completing a design task, such as ideation. This presents interesting opportunities for future design work exploring cognition in heightened design contexts where it could be argued that working memory is loaded.

There is, however, much debate between DPT theorists regarding working memory as it relates to Type 2 processing. Evans and Stanovich (2013) proposed that working memory should be the defining feature of Type 2 processing. Evans (2018) even considers the study of working memory and Type 2 processing to be one and the same. However, such perspectives have been criticised considering the various definitions and models of working memory alongside recent evidence of an unconscious engagement of working memory. Some arguments posit working memory to be a continuum, with more nuance than simply

being engaged or not engaged (Neys 2021; Soto and Silvanto 2014). Despite such evidence, Neys (2021) argues that deliberate thinking can still be conceptualised as requiring greater executive control than intuitive thought. While certain defining features of dual-process theories are under constant criticism, Neys (2021) also believes these debates to be somewhat irrelevant to the progression of psychological theories. Understanding the quantitative or qualitative nature of Type 1 and Type 2 processing is not necessary to determine many insights into our psychology (Neys 2021). Some parallels can be drawn from Neys (2021) to consider the future DPT design research: knowing if Type 1 and Type 2 processing are a continuum or discrete categories is irrelevant to determining whether a dominance of analytic thought leads to more optimal design evaluation than intuitive thought, whether designers are more susceptible to bias when intuiting more, if there are design processes that perform better with more intuition or less, which cues in the design process trigger the switch to more analytic processing, and whether we can optimise designer's reasoning through tools that encourage more or less intuitive or analytic processing.

5.2.2. Self-report measures of DPT

5.2.2.1. Rating scales. Self-report measures have also been successfully applied in the development of DPT in the field of cognitive psychology. Confidence measures have been used as nonverbal measures of cognitive conflict detection. For example, studies have shown that in reasoning tasks where the intuitive response conflicts with the normative response, participants report a decrease in confidence (Neys, Cromheeke, and Osman 2011). Further, when participants are asked to report liking ratings (a Likert scale assessing how liked something is) they assign higher ratings in syllogistic reasoning tasks with believable conclusions than unbelievable conclusions. These studies have demonstrated the importance of metacognition (processes that monitor ongoing thoughts and allocate cognitive resources (Ackerman and Thompson 2017)) in relation to conflict detection, decision-making, and processing effort (Evans 2019).

A recent appeal for a narrower definition of Type 1 processing has suggested that 'autonomous' is too broad a definition (Evans 2019). To address this, Evans (2019) proposes that while Type 1 processes do not burden executive resources or working memory, they do post their products into working memory. It is also proposed that this output is accompanied by a metacognitive 'feeling of rightness' (FOR) – a sense of the correctness of a generated response (Evans 2019; Thompson, Prowse Turner, and Pennycook 2011). A low FOR reflects high levels of uncertainty in a response which can trigger the intervention of Type 2 processing. Such feelings of rightness have been previously discussed in design (Ball and Christensen 2019; Moore, Sauder, and Jin 2014), and are hypothesised to be an indicator of Type 2 engagement (Thompson, Prowse Turner, and Pennycook 2011). That is, a low FOR triggers a greater extent of Type 2 analytic reasoning (Thompson, Prowse Turner, and Pennycook 2011). FOR can also be assessed using a self-report rating scale (e.g. Thompson, Prowse Turner, and Pennycook 2011). This could, for instance, be used in a context where designers are asked to assess their FOR about each newly generated concept.

The metacognitive concept of uncertainty has been used to bridge the internal design cognition to the external design world (Cash, Gonçalves, and Dorst 2023). Furthermore, metacognition has been framed as a key process alongside automatic and analytical processes in a recently proposed 'Triple Process Theory' (Vieira, Kannengiesser, and Benedek 2022; 2023) drawing from Evans's (2019) concept of 'Type 3' metacognitive processes.

Assessing metacognition, uncertainty, and feeling of rightness in the design process is already driving early DPT design research and provides a promising avenue for future applications in the field.

5.2.2.2. Protocol analysis. Protocol analysis – whereby a designer's cognition is examined through the verbalisation of their thoughts (van Someren, Barnard, and Sandberg 1994), is one of the dominant measures within design research (Lawrie, Hay, and Wodehouse 2023). It can be considered a hybrid method of both self-report (as participants report their own thoughts) and behavioural (due to the observational analysis of verbalisations and actions) measures. Considering the extensive use of protocol analysis in design cognition research, its application to DPT-driven design research was an intuitive step. Indeed, recent design research has seen an exploration of protocol coding schemes based on DPT concepts (e.g. Gonçalves and Cash 2021; Vieira, Kannengiesser, and Benedek 2022; 2023). Furthermore, protocol analysis has been used to explore ideation using Linkography, resulting in a Dual Process Ideation model (Gonçalves and Cash 2021). Within this research, consciousness was used to distinguish Type 1 and Type 2 processing (Gonçalves and Cash 2021).

In DPT research, a distinction is often made between the nonconscious nature of Type 1 processing and the conscious nature of Type 2 processing. The problematic nature of relying on these correlates to identify the type of processing has been widely discussed (Evans and Stanovich 2013; Gronchi and Giovannelli 2018), and can be termed the consciousness fallacy. There are obvious challenges to understanding Type 1 nonconscious processes through self-report measures. This is particularly important in the context of protocol analysis. Type 1 processing, by its nature, cannot be accurately verbalised. However, the result of this processing can be verbalised. While a lack of verbal acknowledgement of a design move holds potential for Type 1 attribution, interpreting verbal acknowledgement of a design move as inherently a Type 2 process risks unwarranted attribution of design moves. This is furthered through the key role of Type 2 processing in generating reasons and justifications to rationalise intuitive responses. In protocol analysis, this could appear as a response seemingly developed through Type 2 reasoning which could be a retrospective analysis of a Type 1 response. Despite this, the consciousness of each process does reveal itself differently. In Type 1 processing, only the result of the processing can be considered consciously (Gronchi and Giovannelli 2018; Sloman 2002). Contrastingly, Type 2 processing involves both conscious awareness of the process and the result (Gronchi and Giovannelli 2018; Sloman 2002). Type 2 processing is also dependent on unconscious processes such as the delivery of relevant contextual information (Evans 2010).

Design research has a long history of applying self-report measures (Lawrie, Hay, and Wodehouse 2023). As such, we foresee that the extension of DPT research into design contexts using self-report measures will perhaps require the least effort in reformulating methods by design researchers. However, we caution that research utilising protocol analysis for DPT design research should consider how consciousness reflects each type of reasoning.

5.2.3. Physiological measures of DPT

Physiological measures have been used to dissect the influence of conflict detection (a discrepancy between a belief-based and logic-based response (Evans 2007)) on decision

making. Skin conductance response research has shown that autonomic arousal is tied to the detection of a conflict between a logical and intuitive response (Neys, Moyens, and Ansteenwegen 2010). Interestingly, a participant may detect this conflict and still decide to respond with an incorrect intuitive response to a reasoning task. Therefore, the participant's cognitive ability and individual tendency to engage Type 2 processing determine the likelihood of high Type 2 engagement. However, the use of skin conductance measures in design research poses many challenges. Autonomic arousal can be caused by various stimuli and contextual factors. This makes it an unlikely choice for in-situ DPT design research. However, the method could be applied within more traditional cognitive psychology paradigms such as those used by Neys, Moyens, and Ansteenwegen (2010).

Eye tracking has also been successfully applied in DPT research. Research has shown that participants spend more time looking at the given problem in conflict reasoning tasks over no-conflict tasks (Purcell et al. 2021). This indicates that the length of gaze and the objects of this gaze can be indicators of Type 2 processing depth and engagement (Purcell et al. 2021). Furthermore, eye-tracking has been used to investigate the differences in expertise through a DPT lens (e.g. Gegenfurtner, Lehtinen, and Säljö 2011; Warren et al. 2018). Such research has shown experts have a greater dependency on Type 1 processing regarding the process of visual information than novices. Such paradigms could help detangle Type 1/Type 2 processing ratios in design tasks, how this evolves as expertise is gained, and provide interesting insights into visual processing in design.

The cognitive processes central to DPT descriptions can be assessed in design similarly to how they have been studied in cognitive psychology. Such concepts include: an individual's capacity for detecting conflict between the intuitive and logical response (Bago et al. 2018), preference for intuitive versus analytic processing, and the ability to solve novel abstract reasoning problems (Barrett, Tugade, and Engle 2004). Those cognitive processes that can be measured to identify individual differences in cognitive ability between designers are likely to be invaluable to future design cognition research.

6. Discussion

We propose the roadmap outlined in this paper, and summarised in Table 2, as a guide to applying DPT in design research. Building a substantial body of work that follows a rigorous approach to DPT-theory driven design research, such as that proposed in the roadmap, could provide a basis for extending guidance on conducting and analysing research in this area. The work presented here prompts reflection on practical considerations and implications of future DPT design research. These are discussed in the following sections.

6.1. Practical considerations for DPT-driven design research

DPT provides an advantageous framework for investigating design cognition. To ensure rigour in design research, factors like experimental variables, measures, contexts, and the nature of design must be considered. For example, regarding variables, research has studied design under time constraints, asking questions about the design process while participants are forced to complete 'fast design' (Olesen 2017). Here, researchers control an experimental variable (the time) to study the impact on cognition. Alternatively, methods such as cognitive ethnography have emerged to control for contextual variables (Ball and

Table 2. A roadmap to applying DPT in design research.

Stage	Key activities	Example (Note: this is not an exhaustive list, rather an example set – these will depend on your approach and chosen viewpoint)		
1. Define DPT constructs	Select which DPT model will frame the research	Default-interventionist	Parallel processing	Hybrid model
	Select within the chosen model, the ***defining features*** of Type 1 and 2 processing	Type 1	• Automatic processing • Generates judgement accompanied by a Feeling of Rightness	
		Type 2	• Working memory engagement • Generates decisions accompanied by explicit reasoning or justification	
	Define the ***correlates*** of Type 1 and Type 2 processing	Type 1	• Fast • Nonconscious • Associative • High capacity	
		Type 2	• Slow • Conscious • Rule-based • Limited capacity	
2. Determine research focus	Consider design theory	• Stage of the design process • Structure of the problem		
	Consider design practice	• Expertise • Individual • Collaborative		
3. Select research methods	Consider the use of in situ and/or experimental methods	In-situ		Experimental
		• Protocol analysis • Cognitive constraints (e.g. loading working memory) • Eye-tracking • Rating scales		• Reasoning tasks • Cognitive constraints (e.g. loading working memory) • Eye-tracking • EEG • Rating scales
	Consider types of research measures	• Behavioural • Self-report • Physiological		
	Ensure avoidance of fallacies	• Consciousness fallacy • Normative fallacy • Speed fallacy		

Ormerod 2000), providing a deeper understanding of contextual factors, specifically, collaboration. Expertise, time, and cognitive capacity are other variables that can also affect Type 1 and Type 2 reliance.

Measures used to study design within a DPT framework are also a key consideration. Adapting behavioural, physiological, and self-report measures from cognitive psychology to design, alongside traditional design cognition research methods, offers a versatile array of tools to comprehensively explore design through a DPT lens. Following this, research combining both experimental and in-situ settings emerges as a promising path for developing a comprehensive theory of design founded in DPT. This balanced approach provides mutual validation – experimental testing validated by cognitive studies in in-situ design tasks, and vice versa. Such an approach could boost the overall quality of design research by ensuring both internal and external validity.

The nature of design adds its own challenges – design problems do not have one correct and one incorrect solution (as is relied upon in the traditional deductive reasoning task paradigm). Researchers must then consider reasoning at different phases of the design process and how designers may be relying on Type 1 vs Type 2 processing to make decisions. Additionally, the dynamic nature of design makes the identification of exact instances of pure types of reasoning difficult. Therefore, identifying patterns of behaviour to classify the types of reasoning during design may be a useful initial approach to DPT-driven design research. The design process may also lead to changing susceptibility to cognitive biases throughout the design process and changing tendencies to act on uncertainty or preference of communication style, among others. These variables highlight the importance of considering the design context and of determining how these could be manipulated to test DPT factors.

6.2. Potential implications of design research for DPT

The benefits of applying DPT in design research are clear. However, what can design research give back to DPT? In-situ design applications of the theory, and methodological developments tailored to design, may provide interesting insights into the interactions of Type 1 and Type 2 processing that are not being investigated in experimental cognitive psychology research. Furthermore, applying analysis methods such as creativity metrics (e.g. Shah, Kulkarni, and Vargas-Hernandez 2000) may help connect DPT to design outcomes and potentially reveal a 'golden ratio' of Type 1 and Type 2 processing that leads to positive outcomes. Such work has the potential to influence wider creativity research in cognitive psychology.

Existing design research may provide useful avenues for researching DPT. For example, much of the current design theory discusses the role of intuitive and reflective thought. Intuition gained through experience has been linked to positive design outcomes (Badke-schaub and Eris 2014), while Schön considers a good design process to be reflective. Insights from such work may be useful in forming research questions for DPT-driven design research. Such questions could ask: how do individual inherent tendencies towards intuitive thought (Type 1) in novices play out in contrast to expert intuition, and how is Type 2 processing being used to create good design outcomes that have been connected to reflective thought? This added context and direction from existing work may add to the

potential wider influence of DPT-driven design research. Further contributions to DPT from such design research remain to be discovered.

7. Conclusion

The field of design is seeking change and has spent decades looking for how to develop research with a strong theoretical backing. Some researchers have turned to dual-process theory as the avenue for conducting theory-driven design cognition research. We argue in support of such a direction, albeit with some caution. In this paper, we give a comprehensive overview of dual-process theory to expose the full complexity of the theory and to inform future dual-process theory-driven design research. We urge design researchers to consider the complexities of the theory over the simplifications of the received theory. By doing so, more accurate and comprehensive accounts of design cognition can be realised. This paper also outlines the common pitfalls we have identified in DPT research and formalises paths forward for design research. We present a roadmap of how to apply DPT to design research, considering principles of scientific rigour, with a realistic discussion on how the nature of design itself poses challenges to adopting some research methods. Overall, we hope this paper succeeds in encouraging DPT-based framing of intentional and thoughtful study designs in our research field.

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