REASONING IN DESIGN: IDEA GENERATION CONDITION EFFECTS ON REASONING PROCESSES AND EVALUATION OF IDEAS

Claus L. Cramer-Petersen
clcp@dtu.dk

Saeema Ahmed-Kristensen
sakr@dtu.dk

Technical University of Denmark
DTU Management Engineering, Design Engineering and Innovation
Produktionstorvet, building 426, DK-2800, Kgs. Lyngby

ABSTRACT

Reasoning is at the core of design activity and thinking. Thus, understanding and explaining reasoning in design is fundamental to understand and support design practice. This paper investigates reasoning in design and its relationship to varying foci at the stage of idea generation and subsequent performance of ideas developed. Understanding reasoning in design and its relationship to the performance of ideas generated is important to understand design activity, which can be used to develop tools or methods that can improve the effectiveness of design teams. Protocol analyses were conducted to investigate idea generation sessions of two industry cases. Reasoning was found to appear in sequences of alternating reasoning types where the initiating reasoning type was decisive. The study found that abductive reasoning led to more radical ideas, whereas deductive reasoning led to ideas being for project requirements, but having a higher proportion being rejected as not valuable. The study sheds light on the conditions that promote these reasoning types. The study is one of the first of its kind and advances an understanding of reasoning in design by empirical means and suggests a relationship between reasoning and idea performance. Findings of the study further allows for a way to analyse and improve the performance of idea generation in design teams.

INTRODUCTION

Reasoning is a cognitive activity that dictates how humans respond to situations in every aspect of their lives. Design activity relies on the reasoning processes of designers. Therefore, understanding the role that reasoning plays in design is critical to understand how design takes place. Rittel (1987) states that *"only at the microlevel can we identify patterns of reasoning corresponding to* [the design process]*"* and thus understand design activity. Furthermore, reasoning in design between designers is proposed to take an argumentative form and thus possible to study through design activity between designers (Polk and Newell, 1995).

Reasoning in design has been theorised from a logical perspective according to *abductive*, *deductive* and *inductive* reasoning types (Dorst, 2011; Roozenburg, 1993), suggesting that abductive reasoning is dominant in design. An empirical study in relation to the evaluation of design ideas was conducted, finding that not only abductive reasoning is important to design activity (Dong *et al*, 2012). Hence, a gap is identified in literature on how to empirically study reasoning as it occurs over the course of a design process involving several designers. Furthermore, investigating how reasoning is related to the performance of design outcomes is relevant to explain the effects of different ways of reasoning.

Therefore, this paper seeks to contribute to existing literature by empirically analysing reasoning processes involved in the generation of ideas in real life industrial

development projects. Additionally, the relationship between reasoning processes and the value of ideas resulting from these processes is investigated.

First, the paper reviews and presents existing theories on reasoning and problem solving in relation to design activity and design models. Second, protocol analyses of verbal concurrent data from industry are suggested as a viable method to understand reasoning and relations to performance of idea generation. Third, results are presented and discussed, using qualitative and quantitative analyses to advance theory on reasoning in design. Fourth, the implications of the study contributions are discussed and put into perspective.

BACKGROUND AND THEORY

In the following sections, the background of the study is explained and motivated on the basis of theories and findings from relevant literature. First, reasoning is defined as a cognitive concept and from the perspective of formal logic. Second, reasoning as studied in design is presented through selected models of problem solving and design activity. Third, creative processes involved in idea generation and how such processes can be evaluated are presented. Fourth and finally, similar empirical studies of reasoning and design activity are reviewed.

Cognitive reasoning and mental models

Reasoning is a cognitive activity that decides how humans respond to situations in every aspect of their lives. It consists of trains of thought, including deliberation, arguing and logical inferences. Some reasoning is argued to be largely unconscious, while reasoning also exists in a verbal, argumentative form (Rittel, 1987). Reasoning processes are suggested to be independent from domain or context, but the beliefs and knowledge underpinning reasoning in a certain situation relies on the *mental model(s)* held in a context (Johnson-Laird, 2006).

Mental models are individually constructed working models that allow to integrate information and make predictions about the world (Badke-Schaub *et al*, 2007). Consequently, reasoning is initiated by mental models, but the results of reasoning processes are evaluated according to whether they adhere to one or more mental models (Johnson-Laird, 2006). Thus, while reasoning is initiated in response to a certain context, the result of good reasoning expands the context, resulting in knowledge that influences other mental models (Rouse and Morris, 1986).

Logical reasoning types

Since the works of C.S. Peirce, logical reasoning has been formulated as being of either deductive, inductive or abductive types (March, 1976). Even though their definitions are debated in philosophy, the three types remain a reference point (Kroll and Koskela, 2014). In the following paragraphs, the three types are explained to offer a logical definition as well as interpretation in regards to how such reasoning can be interpreted as cognitive processes.

Deduction

Deduction is the inference of a result from a rule and a case; if a rule known to be true (a law or theory) and a known case (the circumstances that apply) results can be predicted as an effect brought about by a cause (Roozenburg, 1993).

Deductive reasoning is tautological as it allows us to arrive at a conclusion from the logical implication of two or more propositions asserted to be true (Magnani,

1995; March, 1976; Reichertz, 2010). Consequently, deduction is truth-conveying and proves something must be.

Hence, deductive reasoning is analytical and predictive, as it is an explication of an already known or accepted relationship. It is *"the process of establishing that a conclusion is a valid inference from the premises"* (Johnson-Laird, 2006).

Induction

Induction is the inference of a rule from a case and an effect. In the context of research the rule is a hypothesis to be tested, the case comprises the experimentally produced conditions derived from a hypothesis and the result is the outcome of the experiment that confirms the prediction (Roozenburg, 1993).

Inductive reasoning is the process of deriving plausible conclusions that go beyond information in the premises (Johnson-Laird, 2006). Inductive reasoning is tautological like deductive reasoning in that it infers concepts only from available data within a model or frame of reference (Magnani, 1995; Reichertz, 2010; Schurz, 2007). However, inductive reasoning differs from deductive reasoning in that it tests to show whether something is actually operative or true within a model (March, 1976).

Abduction

Abduction is the use of a known principle, law or theory for the purpose of a causal explanation. The rule is given as a premise and allows us to reason from an effect (the results) to the cause (the case). The conclusion of this inference is a hypothesis for a cause to the effect that has to be explained (Roozenburg, 1993).

Abductive reasoning is a process of conjecture that yields an explanation to an event. An abduction is the preliminary estimate that introduces plausible hypotheses and informs where to first enquire by choosing the best candidate among a multitude of possible explanations (Magnani, 1995; Schurz, 2007).

Abduction thus differs from deductive and inductive reasoning in that abductions involve guess work and (sometimes unfounded) assumptions as the basis for reasoning. Within the design field, abductive reasoning has in certain cases also been suggested to involve the conception of new rules or types of relationships to explain an intended outcome. This variation of reasoning has been termed innovative abductive reasoning by Roozenburg (1993) to emphasize the creative outcome of such reasoning (Dorst, 2011; Habermas, 1972; Reichertz, 2010).

Following Pierce, it is suggested that abduction is the only form of inference that introduces new ideas, because induction does nothing but determine a value and deduction merely evolves the necessary consequences of pure hypothesis. Therefore, abductive reasoning is suggested to be the dominant type of reasoning in design activity (Dorst, 2011; Roozenburg, 1993).

Reasoning in design

Reasoning in design has been theorised from the perspective of logics and the terms of deductive, inductive and abductive reasoning (Dorst, 2011; Kroll and Koskela, 2014; March, 1976; Roozenburg, 1993). These theories consider design and its reasoning processes in terms of how design reasoning can be perceived as a logical phenomenon, and are thus not based on empirical data or design in actual practice.

Roozenburg (1993) suggests that truly innovative design is dominated by innovative abductive reasoning. He acknowledges that that while routine design often relies on ideas from e.g. precedent designs, innovative design solutions comprise both descriptions of form and prescriptions of actuation. He exemplifies this with the

imagined first development of a kettle to boil water, which necessitated inventing both a container to hold water in place in parallel with a way to facilitate the user to fill the just developed container with water and heating the water. Roozenburg (1993) defines this synthetic action of both suggesting a new structure and a (supposedly) new principle of heating water on a burner in order to achieve a desired function to be the kernel of the design process. Therefore, innovative design requires both abductive reasoning and a principle that is new to the world.

Dorst (2011) makes a similar argument on the relationship between abductive reasoning and design thinking. He defines design reasoning as the generation of proposals for a 'thing' and a related working principle to achieve an aspired value. This creative feat is done by framing the problem after Schön (1959) to develop a perspective from which the thing and it's working principle can be developed in conjunction to achieve the aspired value.

Reasoning in problem solving

While the previously described contributions on reasoning in design acknowledge that other types of reasoning is present in design (e.g. deductive, inductive) they focus mainly on the reasoning activity of entirely new concepts. Thus, it is relevant to review theories of problem solving and models of design that more fully describe the process of reasoning. This is done in the following.

From the field of cognitive science, Johnson-Laird (2006) describes a generic problem solving cycle as the *"...use* [of*] some constraints to generate a putative solution, and other constraints, such as the goal of the problem, to criticise and amend the results"*. This definition has clear parallels to earlier conception of the types of reasoning involved in the three stages of inquiry: *"Abduction invents or proposes a hypothesis; it is the initial proposal of a hypothesis on probation to account for the facts. Deduction explicates hypotheses, deducing from them the necessary consequences which may be tested. Induction consists in the process of testing hypotheses"* (Fann, 1970, after Peirce).

Thus, the process of reasoning in problem solving can be interpreted as a three stage process involving; 1) an abduction that leads to a certain framing, explicitly or implicitly from mental models, followed by 2) deductions that concretise and predict a solution or effect under the conjectured framing, and finally 3) an inductive reference to principles or accepted facts (possibly 'outside' the framing) that evaluates and tests, leading to a new iteration if the result is not satisfactory.

Models of design

Similar processes to those defined above have been proposed in the following three models of design.

March (1976) suggests the Production-Deduction-Induction (PDI) model, from the works of Peirce, as a rational design process of cyclic iterative procedures characterised by three different types of reasoning:

a) Productive reasoning is the design or *composition* of something novel. It suggests that something may be, and is analogue to abductive reasoning.

b) Deductive reasoning is a *decomposition* comprising prediction of performance characteristics of a design that emerges from analysis of the composition. It proves that something must be.

c) Inductive reasoning is a *supposition* from the accumulation of knowledge and the establishment of values evolving from the prior productive and deductive reasoning. It tests whether something actually is.

Gero and Kannengiesser (2004) argues in their Function Behaviour Structure (FBS) framework for eight processes to be fundamental to all designing. Of these, the first four processes describe a cycle similar to descriptions of reasoning in design:

a) *Formulation* specifies an initial state interpreted from design requirements by transforming a *function* to *behaviour* expected to enable that function.
b) *Synthesis* transforms expected behaviour into solution *structures* that can realise the desired behaviour.
c) *Analysis* derives an actual behaviour from the structure
d) *Evaluation* compares actual behaviour with intended behaviour to make a decision possible.

There is a direct relation between these four steps to the three logical reasoning types.

An alternative model of design is proposed by Hatchuel and Weil (2008). The Concept-Knowledge (C-K) theory assumes "design as an interplay between two interdependent spaces with different structures and logics". C-K theory strongly emphasises the interplay between what is conjectured or unknown and what is known or in existence and describe four operators between concept and knowledge:

a) C-K operators search attributes in K-space that can be used to partition concepts in C. They contribute to the generation of propositions in K, and can be understood as 'design solutions'.
b) K-C operators are symmetrical to C-K operators. They generate tentative concepts from K attributes and thereby assess those new concepts.
c) C-C operators are virtual, and therefore implicit or tacit, and are of importance to the formation of C-K operators.
d) K-K operators comprise logical types of reasoning (deduction, induction, abduction). These operators are possible to run as a program following a formal logic.

Although the three reasoning types are not explicitly mentioned, similarity is interpreted in that operators a and c are abductive, b is inductive and d is deductive reasoning.

The three presented theories emphasise that design thinking features mental activity that concerns (a) the notion something novel and useful which is (b) concretised and explored and (c) evaluated or used to amend the original notion or concept. While the PDI model and the FBS framework presents this as an iterative or cyclic process, C-K theory does not make a-priori distinction between the sequences of the different operators presented by the theory.

Reasoning is argumentative

Rittel (1987) argues that design reasoning is disorderly due to the nature of design problems, where learning about the problem *is* the problem. He further states that by perceiving design as a process of argumentation between people, competing positions and other issues, problems and potential solutions are understood to be debated and developed in parallel (Dorst and Cross, 2001; Rittel, 1987). Analysing such a debate, or dialogue, between groups of people engaged in design therefore holds the potential to understand and explain reasoning as verbal reasoning is the deployment of linguistic processes to satisfy the demands of a cognitive reasoning task (Polk and Newell, 1995). Thus, a key assumption of the study presented in this paper is that reasoning can be identified and analysed through verbal utterances between people.

Even though some reasoning is unconscious, the part of reasoning that is put forward in verbal utterances is suggested to be argumentative (Hogan *et al*, 1999;

Johnson-Laird, 2006). Verbal utterances are suggested to have an illocutionary force, meaning that an utterance holds implicit, culturally defined meaning (Searle, 1979). A study of engineering design conversations conclude that the skill of constructing effective arguments are important, alongside technical or objective grounds, to convey convincing contributions to design activity (Lloyd and Busby, 2001).

Furthermore, studies conclude that the use of initial framing from relevant issues in a design situation guides the following activity (Valkenburg and Dorst, 1998). Therefore, it is important to acknowledge that the way in which a reasoning process starts, is important for the following dialogue.

Creative processes and idea generation

The early stages of idea generation in engineering design designate an important part of the design process. The stage of idea generation is characterised by fewer decisions having been made and thus a greater openness for exploring new and creative ideas. Thus, investigating the reasoning processes of the stage of idea generation is pertinent to understand and support the overall design process. Creativity and the generation of creative ideas are key for the on-going design process and are characteristic of a successful process of idea generation (Cross, 2001).

The standard definition of creativity proposed by Runco and Jaeger (2012), defines creative outcomes to be both *original* and *useful*. Thus, it is relevant to evaluate developed ideas according to their usefulness and originality understood as the practicality of meeting the needs at hand (Keshwani *et al*, 2013; Ward and Kolomyts, 2010).

In engineering design, a common consideration is the trade-off between issues of the key product features (Ahmed *et al*, 2003). Therefore, it is of relevance to investigate the reasoning process in correlation to how ideas are evaluated and under which conditions and constraints the ideas are generated.

Similar studies of reasoning

Similar empirical studies of reasoning in design were reviewed.

Dong *et al* (2012) analysed concurrent verbal protocols of reasoning processes between participants evaluating design ideas and concepts in terms of deductive, inductive and abductive reasoning, defined as: Deductive reasoning as the drawing of conclusion from explicit premises; inductive reasoning as the generalisation from a specific instance: and abductive reasoning as the reframing of users' needs. They conclude that abductive reasoning in evaluating ideas lead to fewer rejected ideas. The opposite was found for deductive reasoning, where more ideas were rejected.

A study by Lloyd and Scott (1994) analysed think aloud protocols of engineering designers for generative, deductive and evaluative reasoning and conclude that experience leads to more generative reasoning and less deductive reasoning, while the opposite is true for novice designers. They interpret reasoning as follows: Deductive reasoning is understanding of and specification of a problem; generative reasoning is presence of a new solution; and evaluative reasoning is reflection on intent and strategy.

A similar conclusion was reached by Ahmed *et al* (2003) in analysing think aloud protocols of novice and expert designers. Additionally, they found an overall reasoning pattern adopted by designers to generate, implement and evaluate decisions, where experienced designers were able to do a preliminary evaluation of decisions before implementation.

Christensen and Schunn (2009) studied the role of mental simulations in design from protocols of concurrent verbalisation of design teams. Mental simulation, interpreted as a reasoning process, was found to reduce uncertainty by turning the uncertainty into approximate answers.

Valkenburg and Dorst (1998) applied Schön's (1959) reflective practice theory to analyse the concurrent protocols of groups of engineering students engaged in design activity. They analyse four primary activities based on *naming*, *framing*, *moving* and *reflecting* according to Schön's theory and conclude that the reasoning process of the groups switches and iterates between reasoning about sub-functions and their integration.

From the literature, reasoning has been reviewed from both a logical perspective and from empirical studies of design. Reasoning from logical literature focus on three primary reasoning types, namely abductive, deductive and inductive reasoning. The reviewed literature on reasoning and cognitive processes in design studies highlights a gap in utilising these three reasoning types to describe design activity. Dong *et al* (2012) have employed the approach, however only on the evaluation of ideas and not on idea generation. Thus, this paper contributes to literature and building of theory through investigating design activity using the perspective of the three reasoning types. In addition, the study focuses on real life development project with design practitioners and not students.

STUDY AIMS

The study aimed to understand how reasoning can be identified and described empirically. The study aimed to investigate and understand the relationship between different conditions for idea generation and the reasoning processes of designers. The third aim was to investigate the influence of idea generation conditions on the evaluation of ideas that are the outcome of these conditions.

Based on the review of literature, the following two sets hypotheses were proposed:

- Hypothesis 1a: *When idea generation conditions are less constrained, a higher proportion of abductive reasoning is expected to initiate ideas.*
- Hypothesis 1b: *In contrast, when idea generation conditions are more constrained, a higher proportion of deductive reasoning is expected to initiate ideas.*

Ideas generated under less constrained conditions are expected to motivate abductive reasoning, since such reasoning relies on possibility and imagination. Idea generated under more constrained conditions are expected to motivate deductive reasoning since the focus is likely be on variations of known solution types and technical principles.

- Hypothesis 2a: *Ideas generated under less constrained conditions are more likely to be evaluated as being potentially highly useful, but too radical for an on-going project.*
- Hypothesis 2b: *Ideas generated under more constrained conditions are likely to be evaluated as being directly applicable to the development project.*

Ideas developed when under less constrained conditions are expected to be dominated by abductive reasoning, as per hypothesis 1a. Thus, resulting ideas are likely to be too radical in relation to the on-going development project. Ideas generated under more constrained condition, are expected to be evaluated as being directly applicable to the project since deductive reasoning is expected to dominate, as per hypothesis 1b.

METHOD

Data was collected through idea generation sessions with real world industry development projects and participants. The data was collected from two SMEs, each of which had already undertaken research into 1) user and customer needs through observations and interviews and 2) product cost factors through benchmarking of competitor products and/or product teardowns. A workshop was conducted with varying idea generation conditions provided in three, half-hour periods. The inputs to these conditions were derived from previous analyses of user and customer needs and cost factors. Generated ideas were evaluated by the participants after the session.

At the time of data collection, both companies were at the stage of early idea generation of on-going development projects, one of these was the design of a support tool for the construction industry, the other a system to compress waste. The workshop designed for data collection was therefore part of the actual product development process and not an artificial task defined for the purpose of the study. Prior to the workshops, the author met with the companies to discuss the primary conclusions of prior analyses and decided on a set of primary set of product requirements from which the idea generation could proceed. Table 1 summarises the main characteristics of the participating companies.

Company	Product type	Number of employees	Participant roles in company	Team size
1	Construction tools	~10	Project manager, design engineer, industrial designer , engineering intern	4
2	Waste management	~80	Head of development, design engineer, production engineer, supply- and logistics manager, mechanical engineering consultant, head of sales	8

Table 1: Case company details

The idea generation session was designed and facilitated by the author and consisted of three rounds of 30 minutes of idea generation under different conditions, simulating varying constraints to the process. These were:

- Round 1 focused on an open brainstorm where existing and new ideas were developed.
- Round 2 focused on meeting user and customer needs without being concerned with cost or other aspects.
- Round 3 focused on reducing cost as much as possible while only not adding functionality in the product or removing not valuable functionality.

The workshops were both audio and video recorded with company participants offered anonymity. The workshops were facilitated to allow the participants to generate many, quick ideas documented on post-its as keywords and/or sketches. These were accompanied by a brief verbal presentation to the other participants.

Each round started with a few minutes spent on individual brainstorming followed by presentation of ideas to the group and later the building on each other's ideas. The facilitator ensured that everyone was heard, that ideas were presented in a sufficient amount of detail and recorded on single post-its. Finally, the facilitator ensured that time was kept and to move the focus of the idea generation across the three rounds

and also in the individual rounds by directing focus on particular components or aspects of the product that had been deemed important from the prior user and cost analyses.

Following the idea generation rounds, the developed ideas were evaluated by the participants. The ideas were sorted in two matrices according to the usefulness and originality of each idea in relation to the on-going development project. Ideas and their evaluation were documented by photographs for later analysis. Table 2 summarises the workshop flow for the generation of ideas under varying conditions and the following evaluation.

Activity	Idea generation			Evaluation
	Open brainstorm	Focus on user and customer needs	Focus on cost reduction	Evaluation of ideas
Example of activity	Documenting and presenting existing ideas	Easy detachment from pulley	How to reduce number of unique parts	Sorting ideas by two matrices
Time	30 minutes	30 minutes	30 minutes	N/A

Table 2: Idea generation session and evaluation overview

Analysis method

Protocol analyses of concurrent verbalisation in the recordings were conducted. Protocol analysis of design activity is a way to understand underlying cognitive processes, e.g. reasoning, with minimal interruption of the recorded process (Ericsson and Simon, 1993; Christensen, 2009).

Protocol Analysis as a method has been recognised in the promise to capture aspects of design activity in great detail given a proper match between data collection design and outcome protocol data (Dorst, 1995). Consequently, verbal protocol analyses of real life industrial development projects is relevant and expected to be highly representative of design cognition found in practice (Ahmed *et al.*, 2003; Chi, 1997; Christensen, 2009). In this case, as the observations were in groups no additional verbalisation is required, hence a minimum of interference with thought processes.

Coding scheme development

The protocols were coded according to a coding scheme drawing from existing studies and adapted to the protocols of similar data-set also collected by the authors.

The protocols were segmented and highlighted for indicator words. In the first round in the coding all segments were coded for the presence of an idea or and idea aspect (Badke-schaub *et al*, 2007). Next, the segments were coded as abductive, deductive, inductive or no reasoning. Table 3 below shows the coding flow, before describing the coding process in further detail.

Coding step	1 – identifying ideas	2 – classifying reasoning
Code list	IDEA	ABDUCTION
	IDEA ASPECT	DEDUCION
		INDUCTION

Table 3: Coding process overview

To ensure that ideas and reasoning processes could be captured in the coding process, the entire protocol was segmented and analysed (Chi, 1997). The segmentation was conducted to ensure the data analysis was manageable in relation to both size and intention of the participants to allow coding of ideas and reasoning processes (Christensen and Schunn, 2009; Goldschmidt, 1991). Hence, it was possible to analyse the utterances by the shortest practical elements of meaning. The reasoning steps are elaborated in the following sections.

Coding idea and idea aspect

The first step of analysing the protocols involves the identifying of ideas uttered by the groups. In the online dictionaries, ideas are commonly defined as concerning: 1) A course of action, 2) a basis on something believed valid and 3) an imagined outcome (Merriam-Webster; Oxford).

In engineering design research, ideas are similarly defined as: an external perspective: *"an idea as a solution to a single function"* (Linsey *et al.*, 2011), *"idea as notion related to a task"* (Goldschmidt and Tatsa, 2005), as a solution for a problem or sub-problem (Badke-schaub *et al.*, 2007). These perspectives have in common that an idea is a proposition for a solution to a function, involving intentional work (the task).

As ideas involve solutions and sub-solutions (Badke-schaub *et al*, 2007), it is necessary to perceive ideas as being put forward in a distributed manner, and at different levels of abstraction (Voss, 2006). Furthermore, ideas are not necessarily put forward by a single person over the course of conversation, but can be elaborated by other persons than the one initiating it. Consequently, the protocols will not be distinguished by a complete uninterrupted utterance, but rather a group of utterances relating to an idea put forward and related aspects of that idea. This group of utterances, and belonging segments, are hereafter referred to as *idea episodes* (Chi, 1997). These definitions were the basis of coding ideas and idea aspects.

Reasoning definitions and indicators

An initial coding scheme utilising *case*, *rule* and *result* from a logical perspective of reasoning suggested by Roozenburg (1993) was first employed, but abandoned due to poor coder reliability because definitions were unclear in the verbal protocol.

Instead, definitions of what characterises the different types of reasoning were derived from theories of reasoning processes and models of design activity presented in the earlier sections. The definitions used were oriented towards the suggested role or function that the three types of reasoning serve in reasoning processes. Refer to table 4 below for the full definitions used for coding.

Reasoning type	Coding definitions
Abduction	• A hypothesis or assumption to account for what is observed or what is desired or intended • Creating ideas (to a problem) from imagination • A belief held without proof or certain knowledge • Preliminary guess to introduce hypotheses
Deduction	• Definitive and certain conclusion • Explicating hypothesis by suggested consequences • Prediction of result in a given frame • Proves something must be • Explores consequences of an abduction

Induction	• Tests a hypothesis with available data (predictions) • Generalises from specific instance or idea • Evaluates if something is operative • Inferring from observed to unobserved • Inferring about future courses of events
References	(Fann *et al*, 1970; Johnson-Laird, 2006; Magnani, 1995; March, 1976; Reichertz, 2010; Roozenburg, 1993; Schurz, 2007)

Table 4: Reasoning type and definitions for coding

To support the coding of reasoning types, a data-driven approach was taken by reviewing the transcripts for the presence of any common features of segments initially evaluated to belong to the different type of reasoning. This process resulted in the identification of three groups of indicator words that signify the three different types of reasoning. A similar approach was adopted, amongst others, by Christensen and Schunn (2009) in the analysis of verbal concurrent protocols. The words were derived in Danish, as the data was in Danish and all analysis was completed in the original language. The full list of indicator words is translated to English for the purpose of reporting in table 5.

Reasoning	Abduction	Deduction	Induction
Indicator words	*could, maybe, think, could be, imagine, probably, likely*	*so, then, therefore, that is, must be, as, can*	*I, me, you, they, we, them*

Table 5: Reasoning indicator words.

The common characteristics for the indicator words were as follows:
- Abductive reasoning: Conveys uncertainty, possibility and serves to frame the elaboration of an idea on the remaining segments of an idea episode.
- Deductive reasoning: Co-occur with segments and words which convey a conviction, justified belief or consequence in response to a situation.
- Inductive reasoning: Often comes after the idea episode is finished and tends to co-occur with the use of pronouns (e.g. *I, you, we*) as a way for a person to judge or qualify an idea.

Coding reasoning types

The segments coded for idea or idea aspects were then coded for using abductive, deductive or inductive reasoning. Induction codes could also be applied to segments outside the idea episodes, as they were often realised as delayed evaluations of an idea.

To check for reliability of the coding scheme, a second researcher coded the segments and an inter rater reliability score was calculated using Cohen's Kappa. The coding of idea episodes reached a Kappa of 0,71 based on 460 segments and coding of reasoning type reached a Kappa of 0,61 based on 353 segments. Both scores are deemed good and hence justify the application of the coding scheme in the present study.

Idea evaluation

After the generation of ideas, they were evaluated by the participants. The frame of reference for evaluating the ideas was the on-going development project.

Each idea was evaluated in a two-by-two matrix. The criteria were a high/low fit to the primary product requirements (on the vertical axis) and whether the idea would provide a high or a low value for the customer/user (on the horizontal axis). Ideas evaluated high in both axes (i.e. the top right quadrant) were moved to the second matrix for further evaluation.

The second two-by-two matrix distinguished whether the idea had a high/low value to the company (on the vertical axis), and according to low/high risk, complexity and/or development effort (on the horizontal axis). Ideas evaluated positively on both axes were accepted directly for the further design process.

The first matrix evaluated the value to the user/customer. By evaluating according to the on-going project, ideas were filtered to only those with immediate potential for realisation and thus innovative potential (Ward and Kolomyts, 2010). The second matrix evaluated ideas according to their usefulness to the development project by filtering ideas that would require too much further analysis or ideas that had a low value to the company in general.

RESULTS AND FINDINGS

A total of 3760 segments and 155 idea episodes were coded and it was found that reasoning occurred in 51% of all segments and in 89% of segments coded for the presence of ideas or idea aspects. Other non-coded segments could be explanations, team coherence, informal talk, etc., but these were not coded or analysed. Table 6 shows the total distribution of reasoning of the two protocols.

Reasoning type		Abduction	Deduction	Induction
Coded reasoning	Count	248	1367	321
	Frequency	13%	71%	16%
Reasoning in start of idea episode	Count	66	72	15
	Frequency	43%	47%	10%

Table 6: Distribution of reasoning in both analysed protocols

Reasoning in design

Perhaps surprising is that abductive reasoning is the least frequent type of reasoning in the protocols. However, when investigating idea episodes, it is clear that abductive reasoning only requires few statements to hypothesise and introduce new frames of understanding the problem. Consequently, the high proportion of deductive reasoning is explained from the observation that deductive reasoning often come in series of several statements about the structure of an idea, often following directly from abductive reasoning statements. This is particularly evident when observing the higher proportion of ideas initiated by abductive reasoning, as also shown in table 6. Inductive reasoning was found to occur in more segments than abductive reasoning, but is often embedded in an idea episode or follows after episode end.

In the following, two examples of idea episodes are presented to illustrate and further discuss the data. Both examples are translated from Danish to English for the purpose of reporting.

Speaker	Segment	IDEA	IDEA ASPECT	REASONING TYPE
A	Then I am thinking,			
A	if you could minimise the entire pulley	x		ABDUCTION

Speaker	Segment	IDEA	IDEA ASPECT	REASONING TYPE
				ABDUCTION
A	or then just have a reel or a caster	x		ABDUCTION
A	that you find on the American solutions,	x		DEDUCTION
A	but then you just do a pre…	x		DEDUCTION
A	use a bit more to prepare	x		DEDUCTION
A	so you drive it to the window, find the right distance, mount it	x		DEDUCTION
A	and then you just have to lift it 3-4 cm	x		DEDUCTION
A	and then you have the adjustment and lift it again	x		DEDUCTION
A	so you minimise the entire phase of pulling and lifting	x		DEDUCTION
A	so you just do it manually	x		DEDUCTION
B	It could also be that you used the pulley to drive the wheel,	x		ABDUCTION
B	so you extend it, attach the hook [inaudible]	x		DEDUCTION
B	oh wait no, but, well…	x		
B	it is silly as it is now			INDUCTION
B	but it could be with the same motor		x	DEDUCTION
B	when it is attached to the cart base		x	DEDUCTION
B	then there is some sort of gearing to the wheel,		x	DEDUCTION
B	same engine drives and pulls…		x	DEDUCTION

Table 7: Example of idea episode initiated by abductive reasoning

The example presented in table 7 was taken from the protocol of company 1 and was presented under condition 3, with a focus on cost reduction. The example illustrates how multiple instances of reasoning take place during the generation and elaboration of an idea. The idea is initiated by abductive reasoning that states an intention to achieve a function. Following the abductive reasoning, deductive reasoning is used to explore and suggest how to achieve the intention of the abductive reasoning. The deductive reasoning is switched to abductive reasoning again when a different participant offers an alternative function of the pulley. Following this is further deductive reasoning and an instance of inductive reasoning in the form of a negative evaluation of an existing product.

Speaker	Segment	IDEA	IDEA ASPECT	REASONING TYPE
C	I have written that we can bolt it together instead of welding	x		DEDUCTION
C	I know we had one before,			
C	that was split in two and then, pfff, [gesticulates assembling the two parts] and so forth.		x	DEDUCTION
C	For instance today, the hinges, they are welded on,		x	DEDUCTION
C	The ones we have on the B3 and B5.		x	DEDUCTION
C	But the hinges we have on the newer models,		x	DEDUCTION
C	they are actually bolted on.		x	DEDUCTION
C	It's an advantage in relation to changes right and left		x	INDUCTION

C	And it gives advantages in relation to adjustment		x	INDUCTION
D	And it will exempt it from that part of assembly.		x	INDUCTION

Table 8: Example of idea episode initiated by deductive reasoning

The example presented in table 8 was taken from the protocol of company 2 and was presented under condition 3.The example illustrates how ideas are also initiated by deductive reasoning. This idea follows a different pattern than the one above because it first states, deductively, how one fastening principle is better than an existing one. Then follows more deductive reasoning similar to the previous example, and finally a number of inductive statements are used to justify the initially proposed idea by referring to a customer need (the ability to easily switch the direction the door opens) and an advantage in the assembly of the product (easier adjustment).

Comparing the two examples, it is evident that both use a series of deductive reasoning to argue for and detail some technical principle. What differs between them is that the first example starts from stating what the idea should achieve (i.e. a function) and then goes on to search for ways of solving it. The second example, on the other hand, starts without mentioning what the idea is supposed to achieve in an explicit sense, but rather moves on to argue and evaluate the idea function at the end of the reasoning process.

<u>Reasoning in design activity</u>

The examples show that the first instance of reasoning in an idea episode functioned to set a frame that either relied on an assumption in the first example, or a definite statement about preference in the second example. By reviewing multiple examples as the ones just given, it is argued that the first reasoning of an idea episode has a determining effect on how the remaining episode progresses. This finding is comparable to the notions on framing and *primary generator* in design activity, albeit at a micro-level of reasoning (Darke, 1979; Valkenburg and Dorst, 1998).

Reasoning was found to occur in sequences of alternating reasoning types. An implication of this is that empirical indications are found that problem solving can be said to follow patterns similar to those suggested by models of design and problem solving (Ahmed and Aurisicchio, 2007; Gero and Kannengiesser, 2004; Hatchuel and Weil, 2008; Johnson-Laird, 2006; March, 1976).

Taking a different perspective on the ideas developed, the protocols also suggest that the ideas generated follow different patterns. Some ideas are indeed dominated by abductive reasoning and go through several abductions to hypothesise how to go about solving a problem. Oppositely, ideas were also found to be developed strictly by applying deductive reasoning. This shows different approaches as being similar to findings by Ball and Ormerod (1995) suggesting that problem solving follows both *breadth-first* and *depth-first* strategies to the development of solutions. The finding also highlights that reasoning in design is not an orderly process, but proceeds following varying sequential patterns, as also suggested by Rittel (1987), and C-K theory (Hatchuel & Weil, 2008).

Reasoning under varying conditions

In this section, results on how reasoning patterns change during the different conditions of idea generation are presented and discussed.

To reiterate, the data was collected from ideas generated under three different conditions:

- Condition 1 was without a particular focus and encouraged the participants to document existing ideas, and generally to develop ideas without further instructions
- Condition 2 emphasised to focus on user and customer needs by developing ideas that sought to fulfil those needs in the best way possible without regard for cost or other uncertainties
- Condition 3 emphasised focusing ideas generated on reducing the cost-price of the product while only maintaining a minimum of functionality.

Figure 1 below shows the proportion of reasoning types used to initiate idea episodes across the three different conditions. A one-way ANOVA analysis was completed for each condition (p-values reported in figure 1). Confidence intervals from the ANOVA ($p = 0.05$) were added and displayed as error bars. Sample size is displayed above each bar. As expected from hypotheses 1a, there is a trend, however not significant, in the data that a higher proportion of abductive reasoning is used to initiate ideas under condition 2, while there is a significantly higher proportion of ideas initiated using deductive reasoning under condition 3, thus supporting hypothesis 1b.
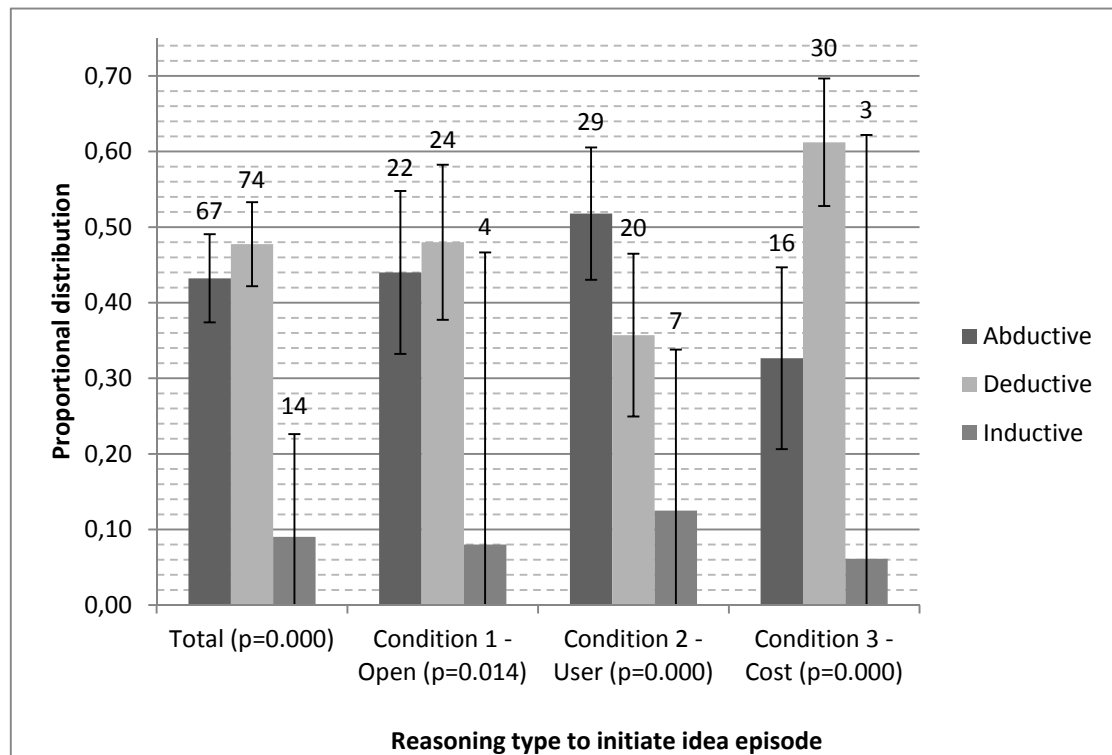
Figure 1: Comparison of reasoning type under the different conditions

The differences in proportions under condition 2 were found to be close to significant given the relatively small sample size. Therefore, it is expected that adding more cases to the study will result in significance. Furthermore, it is observed that ideas developed under condition 1 are almost exactly equal to the total means, thus emphasising that conditions 2 and 3 alone account for the changes in reasoning patterns of the participants, and in different ways.

Investigation of the qualitative difference in reasoning under the different conditions suggests that under condition 2, where user and customers are in focus, ideas introduce solutions based on more radical principles and assumptions,

promoting abductive reasoning. Also included are ideas that are known from products of other types, but not previously applied within the company's industry. Under condition 3, where cost reduction is in focus, ideas were often developed by drawing on already known techniques and approaches to production, manufacturing and material selection, promoting deductive reasoning. Surprisingly, only few of the ideas generated suggested to lower the level of functionality in relation to the user as a means to reduce product cost.

Idea evaluation

Finally, an analysis of the relationship between idea generation condition and idea evaluation was conducted.

A total of 155 idea episodes, possibly containing several idea aspects, were coded and 213 ideas were evaluated. This difference was explained by the coding methodology, where sometimes one idea episode could be documented on several post-it's that would later be evaluated individually. This could distort the results if there are strong correlations between the average episode length and reasoning type, condition or idea evaluation. However, as table 9 below shows, the differences in average idea episode length and the ratio of coded ideas to evaluated ideas were not dramatic, and are not a feature of one single condition.

Condition	1	2	3
Ratio of coded idea to evaluated idea	81%	68%	71%
Average episode length	25,2 segments	23,6 segments	24,5 segments

Table 9: Differences between conditions in relation to episode length and ideas

Idea generation condition effects on idea evaluation

The data was analysed to investigate the relationship between idea generation conditions and idea evaluation. Table 10 presents an overview of how all of the ideas were evaluated. As can be seen in the table, ideas evaluated to be rejected in the second matrix and ideas evaluated as maybe relevant only occurred in few numbers and only under condition 1.

Idea evaluation	First matrix		Second matrix				Total ideas
	Reject	**Radical**	**Reject**	**Maybe relevant**	**Analyse**	**Accept**	
Condition 1	3	14	3	1	9	31	61
Condition 2	15	27	0	0	11	30	83
Condition 3	20	7	0	0	11	31	69

Table 10: Overview of evaluation of ideas

To allow for a better overview of the distribution of idea evaluation under each condition, figure 2 presents the four kinds of evaluation that accounted for 98% of all evaluated ideas. A one-way ANOVA analysis was completed for each evaluation type (p-values reported in figure 2). Confidence intervals from the ANOVA ($p = 0.05$) were added and displayed as error bars only on 'Reject' and 'Radical' evaluation since the proportions of 'Analyse' and 'Accept' evaluations were not significantly different as per the ANOVA. This is explained by the almost equal proportions in those groups. Sample size is displayed above each bar.

The relation between ideas evaluated as being too radical shows a trend towards what was expected from hypothesis 2a, stating that idea from condition 2 are more likely to be evaluated as being highly valuable, but too radical for the current development project. However, due to low sample size, the difference was not significant. For hypothesis 2b, it was not found that these ideas developed under condition 3 had a higher proportion of acceptance.
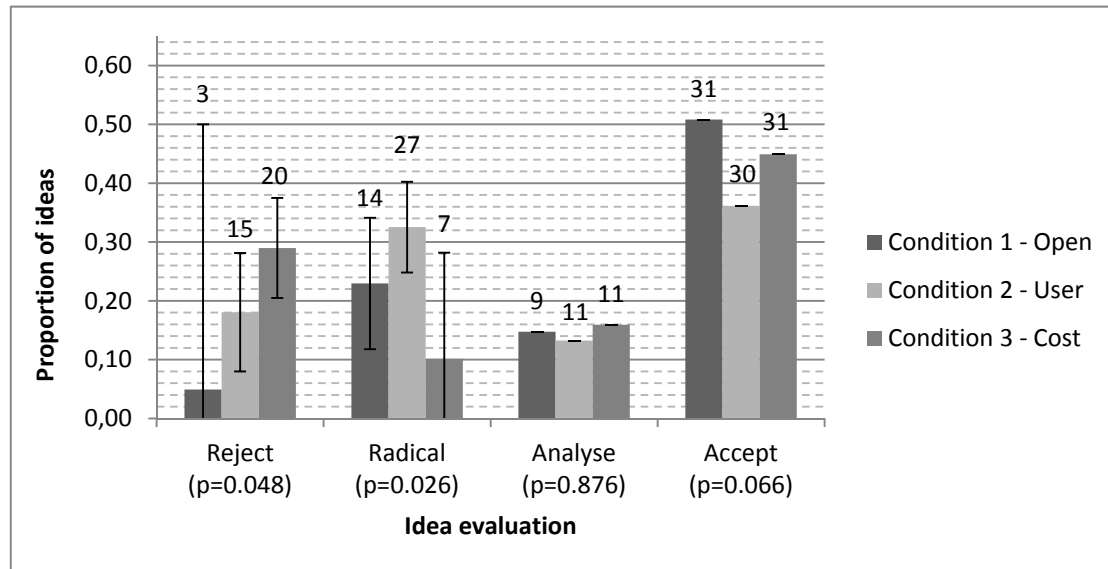
Figure 2: Significant differences in how ideas are evaluated across the different constraints.

From the analysis it was found that there is an opposite relation, however not significant, when it comes to the proportion of ideas being rejected. Here, ideas from condition 3 show a trend of having a higher proportion of ideas rejected. This can be explained as a consequence of the lower level of originality displayed by ideas under condition 3, which result in ideas being rejected. There is a very low proportion of ideas from condition 1 rejected, and this is attributed to the earlier described interpretation that this condition was dominated by existing ideas, which are more likely to be accepted as they are already known to the participants.

Despite the different reasons for ideas not accepted, the overall proportion of ideas from the different conditions being accepted are not significantly different in proportion, and very equal in amount of accepted ideas (see figure 2). Instead, the analysis unveils that ideas are rejected for different reasons.

Bringing these results together with the previous analyses highlights that the focus upon customer and user promotes abductive reasoning, which in turn leads to more valuable but too radical ideas. In contrast, is shown that when focus is on cost reduction deductive reasoning is promoted, which in turn leads to more ideas being rejected because they do not add value to the project. A similar result was found by Dong *et al* (2012) where deductive reasoning lead to higher rejection rate in the evaluation of ideas.

DISCUSSION AND CONCLUSIONS

A study of design activity, as part of real life product development processes in two companies, was conducted. Reasoning patterns of idea generation processes

observed under three conditions for generating ideas and the evaluation of the generated ideas were investigated.

Reasoning patterns involved in the generation of new ideas were identified to utilise abductive, deductive and inductive reasoning. Additionally, reasoning was shown to occur in sequences alternating between the different reasoning types to form arguments for an idea in generation. Hypothesis 1a stating that a higher proportion of ideas developed under less constrained conditions was not significantly supported, but showed a trend in the data that would likely find support for the hypothesis given a larger sample size. Hypothesis 1b stating that a higher proportion of ideas developed under more constrained conditions was significantly supported. Hypothesis 2a stating that ideas developed under less constrained condition were more likely to be evaluated to be too radical for the on-going development project showed a trend in the data, but was not significant. Hypothesis 2b stating that ideas developed under more constrained conditions were more likely to be evaluated to directly applicable to the on-going development project was not supported. However, it was found that a higher proportion of these ideas were evaluated as not being valuable to the project.

The study reported here is one of the first studies of the kind for two primary reasons. First, it is shown empirically how reasoning in design follows different patterns in the form of sequences between alternating types of reasoning. Second, a relationship between reasoning patterns and the evaluated value of developed ideas is suggested to be mediated by the constraints and conditions under which the ideas are generated.

Three of the four hypotheses did not show significant differences. This is attributed to the low sample size, and therefore highlights the importance of conducting more cases, which is a first priority in future research.

Implications and further research

From a managerial perspective, understanding how reasoning and constraints influence design activity support the management of creative processes in organisations. For example, further development of the study could be the underlying basis for:

- The application of creative methods to increase the output of idea generation sessions in industry
- The recruitment and assessment of employees by testing or training reasoning skills

In relation to design education, the findings of the study could be used in the teaching of students to improve reasoning skills to improve design competences.

From a research perspective, an understanding of the relationship between reasoning, idea generation conditions and evaluation serves as a foundation for understanding design activity and human behaviour in design. Directions for future research could include:

- Adding more cases to the analysis to further investigate the hypotheses of the present study (this is in progress)
- Understanding the direct relationship between reasoning patterns and idea evaluation by analysing reasoning pattern and idea on a one-to-one basis
- Understanding how to increase number of generated ideas that are accepted and valuable to a development project.

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