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ABSTRACT

This paper is a theoretical approach to structure design-specific knowledge into a framework, which can be used within the context of organizational and societal development. We conducted an extensive literature review about existing definitions of design knowledge, and knowledge in general. Based on this, we developed a typology, which consists of four different types of design knowledge and three interjacent transitions. According to our proposed framework, design knowledge can be represented in physical artifacts, as tacit gut feeling, as codified knowledge, or as scientific theories. To illustrate further we present examples for each knowledge type and transition and we suggest prototypical approaches for transferring these types of design knowledge in the context of design education. We believe this paper contributes to a better understanding of design knowledge, and our suggested framework might serve as a foundation for further design research, and for developing IT-systems to support design processes.

Keywords

Design Knowledge, Knowledge Management, Design Education, Design Science, Knowledge Transfer

INTRODUCTION

While in many disciplines Knowledge Management is already established as an important factor aiming at preserving knowledge or transferring it within organizations or between teachers and students, in the field of design the research about this topic is still at the beginning. But particularly design-specific knowledge has certain characteristics, that make it difficult to transfer, e.g. if it is not represented in a codified form.

A better understanding of design knowledge—different types and their characteristics—might be helpful for design practitioners and educators. For example, the design of exercises in design education depends a lot on the question, what kind of knowledge is supposed to be transferred, and what the student should learn from the assignment. Moreover, in the field of IT-supported design (e.g. brainstorming tools or modeling), different types of knowledge could be addressed in different ways.

But what exactly is design knowledge? There are many different aspects of design knowledge, which every teacher and design practitioner can probably imagine, such as modeling skills, gut feeling, rules and heuristics such as design patterns or ergonomic norms. And there is knowledge about design history, about specific design methods, processes or production techniques. Some information might be even embodied in physical products—a specific shape that serves a specific purpose. Some of these knowledge representations can be easily transferred, since they are explicitly codified as facts and figures. Others are better described as vague feelings that one design is better than another one—which is quite difficult to transfer to a student (Ashton, 2007).

What is missing is a common and well-structured framework of the different types of design knowledge, including information about their representations and properties, as well as about the different requirements for transferring them. A lot of research has been done about design knowledge, so far (see section "Related Work" for details), but unfortunately most of the publications make use of their own terminology, or focus only on partial aspects of design knowledge. To the best of our knowledge, there is no such thing as a common and comprehensive framework about design-specific knowledge that could be used as a foundation for further research in that topic.

This paper addresses this challenge. The first section "Knowledge in Design Science" is the main part of this article. First, we discuss different theories about knowledge in general, before we adapt one of these theories—a knowledge model by Radermacher—to develop a framework for design-specific knowledge. We also offer suggestions how to transfer the different types of design knowledge to students.

The second section "Related Work" is placed at the end of the article, since we need to introduce our framework first, in order to discuss the related work according to our framework. We analyzed 17 scientific papers covering the topic of design knowledge and highlighted differences and similarities with our framework.

KNOWLEDGE IN DESIGN SCIENCE

Knowledge Models

There are numerous theories and definitions about what knowledge actually is (for an overview see e.g. Maier, 2002).

In the classical philosophical definition—as expressed in the Socratic dialog "Theaetetus"—knowledge is described as "justified, true belief" (Plato, 2008). However, this definition is too narrow for our purpose, because it excludes all knowledge that cannot easily be justified, like gut feeling or design intuition.

Another common approach is to make a distinction between knowledge, information, and data. Aamodt and Nygård (1995), for example, use semiotics to differentiate between these three. If there is a syntax that regulates the correct combination of signs, we call the signs data. Data needs semantics to become information. If information is connected with other information, embedded in a context, and applicable to achieve a goal—that means it has a pragmatic dimension—it is called knowledge (Aamodt and Nygård, 1995). Thus, knowledge provides the ability to perform effective decisions and actions.

Radermacher (1996) introduced a system-theoretic view of general knowledge processing, which is inspired by biological systems and biological evolution. Radermacher's model uses a broad concept of knowledge, wherein all patterns that enable actions or decisions are called knowledge. It differentiates between four levels of knowledge processing (see Figure 1). These levels evolved one after the other and are also built up materially on each other. Knowledge is represented at all levels through the construction and the transformation of patterns. The representation of those patterns, however, differs with each level (see Figure 1).

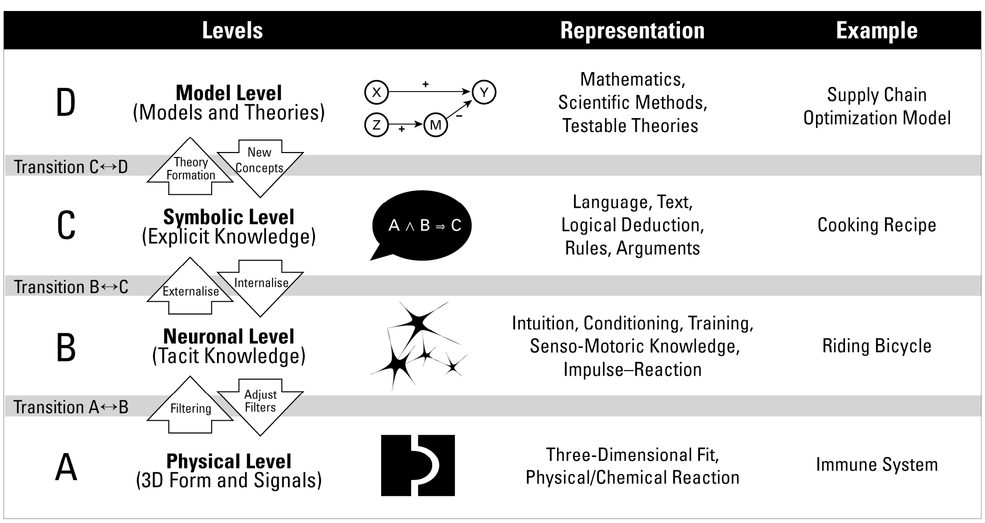

Figure 1: Four-Level Framework for General Knowledge, based on Radermacher (1996)

We decided to refer to Radermacher's model of knowledge and to use it as a basis for our model of design knowledge, because it is the most comprehensive model of knowledge we found, and it covers all knowledge aspects that we think are relevant for the specific properties of design. Moreover, Radermacher's framework also highlights the importance of the transitions between the different levels of knowledge, and gives some hints about the transformation mechanisms.

Framework of Design Knowledge

Design knowledge is a specialized form of knowledge—knowledge about design. As mentioned before, we developed a framework of design knowledge, which is based on the knowledge framework of Radermacher. Figure 2 shows our suggested framework of design knowledge. In the following, we describe the four levels of design knowledge and the three transitions in detail. We describe the level according to Radermacher's model, then we highlight the special characteristics of design knowledge, and then we present some thoughts about transferring respectively teaching these types of knowledge.

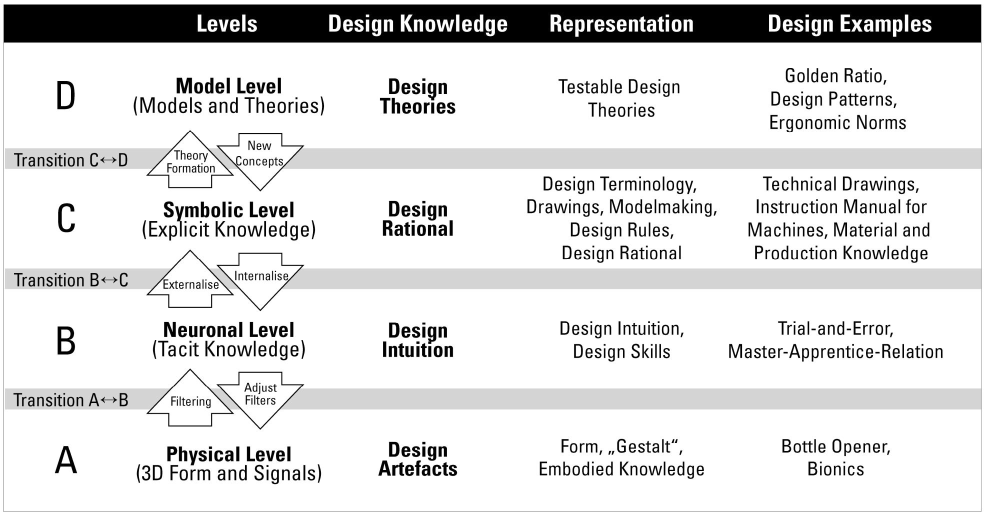

Figure 2: Four-Level Framework for Design-Specific Knowledge

Level A: Physical Knowledge or „Embodied Knowledge“

This level consists of the physical or signal level. The knowledge is represented in the form of a three-dimensional fit or a physical/chemical formation. An example is the immunological system that works on the basis of a key-lock-principle. The "knowledge" of the immunological system about past infections and the proper reactions is captured in the physical/chemical docking capability of an antibody with a virus.

Adapting this concept for design, we call this level **"Design Artifacts"**. Cross (2004) makes use of the term „embodied“ knowledge, i.e. knowledge about a specific handling, usage or function that is „frozen“ in the physical form of an object. The solution of how to open a bottle, for example, is inherent in the form of the bottle-opener. Another example is the concept of bionics. Certain properties of nature can be copied and transferred into designed products, just as the knowledge of the functioning of the botanic burdock is embodied in the designed shape of Velcro fasteners.

The representation of knowledge in artifacts seems quite obvious and useful for transferring design knowledge: the knowledge of a historic designer, embodied in his/her products, remains, even though the designer may have passed away long ago. Using that physical knowledge and re-engineering it from the object, seems to be a very promising method for extracting knowledge and transferring it to the design students. Learning from good (and bad) design examples will surely add to the students' understanding of design.

Transition A↔B

Since our environment is overloaded with signals from the physical level, we need filters to select, out of all possible signals, only those that are relevant for us. In the reverse direction, these filters can be adjusted, to allow only certain signals to be processed.

Adapting this transition to design, we stick to Radermacher's terms **"Filtering and Adjusting Filters"**. Signals from the physical level are filtered, or the designer's perception of the environment may be adjusted during this process. Designers should be able to look at the world differently: they need to see things (problems, opportunities, etc.) that other people don't notice.

The Transition A↔B is aimed at changing the students' perception of their environment. The manner whereby signals from the physical level are processed, is supposed to be adjusted through e.g. filtering. Many known exercises from design education make use of this concept, e.g. by suppressing part of the student's senses in order to sharpen the others.

Level B: Tacit or Neuronal Knowledge

This level uses neural networks or "holistic methods" to process input. The knowledge is represented as a (dynamic) equilibrium of activity levels in a neural network (Russell and Norvig, 1995). All sensorimotor knowledge that enables humans (and animals) to perform complex body movements, e.g. riding a bicycle, can be placed at this level. Also the intuition of an expert in complex situations falls into this level. Gladwell (2005) presents numerous examples of how experts make complex decisions in a "blink" of an eye. Often the quality of their decisions is comparable with those that follow from extensive analysis. The same experts, however, were often incapable of explaining why they settled on a particular choice. Rather than a set of explicable rules, the experiences of the experts are stored in a more holistic or "neural network" manner. Similarly, artificial neural networks do not have the capability to "explain" their outputs, and humans are not capable of understanding the meaning of a neural network representation (Russell and Norvig, 1995: p 592). The tacit dimension of knowledge from Polanyi (1966) can therefore be placed in this level. Tacit knowledge or intuition usually evolves from experience and practice. An (artificial) neural network can be trained by examples and is then capable to generalize the learned patterns to similar situations (Russell and Norvig, 1995). The more you ride a bicycle, the more you internalize how it works. Depending on your movements on the bike you get different feedback from your environment (i.e. reaction of your bike). The connection between your actions and the results is represented in a holistic neural network pattern. One rides a bike not by solving physical equations but by using sensomotoric intuition. The more relevant action-feedback cycles you experience, the more developed your neural generalization becomes, and the better your intuition—and your riding—become.

Adapting this level to design, we call it **"Design Intuition"**. The intuition of a designer for good design is based on the neuronal level of design knowledge. Sometimes a designer cannot explain, why a design is good or not—they just „know" because of their gut-feeling. This intuition or tacit knowledge needs to be trained, e.g. through trial-and-error, through variations and test-series, or just by experience. Another possible way to build tacit knowledge is through observation and imitation. Recently, neural science discovered that this could be explained by the so-called mirror-neuron system (Rizzolatti and Craighero, 2004). When someone observes an action being performed, neurons in their brain fire as if they were performing the action themselves. Therefore simply being in a relevant environment and observing an expert designer could lead to enhancing the design intuition.

When learning to ride a bicycle, we make use of various "safety nets", e.g. extra wheels that reduce the complexity of riding the bicycle, and react to feedback from the bike itself in a holistic way. We learn, for example, that a specific movement might cause the bike to fall. In design teaching, we can also make use of a "safety net", by reducing the parameters (e.g. by removing or fixing choices for a design assignment), or by reducing the complexity of the task. Feedback can be either counseling from the teacher (while the feedback in this level is not a codified design rational but mainly a distinguishing between "good" and "bad"), or it can be given from the artifact itself (e.g. ceramics that break when reaching a minimum thickness). The development of design intuition through project work, learning-by-doing, or trial-and-error exercises with additional counseling through the teacher constitute a majority of design education (Dorst, 2003b: p 86).

Transition B↔C

In the transition from Level B to Level C, a classification of world and mental states to concepts is taking place. People agree on a common language, and tacit knowledge is externalized, e.g. by codification and transformation into written or spoken language. As before, this transition also proceeds in both directions: Moving upwards, from B to C, the tacit knowledge is codified and externalized (e.g. written down); moving downwards, explicitly codified knowledge (e.g. traffic rules you have learned in driving school) can be internalized, such that they can be recalled without even thinking about them (Nonaka, 1994).

In the context of design, the tacit knowledge from Level B becomes externalized into codes and symbols. This codification could be the agreement on a design terminology, the learning of design-specific expression skills (such as drawing or modelmaking), or reflecting upon previous tacit experiences, by verbalizing and discussing them (Schön, 1983). In the other direction, explicit knowledge can be internalized by frequent application.

In design education, the Transition B↔C aims at the agreement on a common design language. This includes the building of a design terminology, as well as the training of design-specific expression skills, such as visual languages, or the use of spatial software. However, another very important factor for design education is the reflection of previous work (Schön, 1983), which falls also into this transition: the gut-feeling from the adjacent Level B needs to be externalized, in order to reflect and learn from the Level B-experiences. Without the ability to transfer the intuition from Level B to the next level, namely to be able to verbalize and reflect on them, the whole concept of 'learning-by-doing' is less effective (Dorst, 2003b: p 87).

Level C: Symbolic Knowledge

The third level is knowledge in the form of language, logic, and symbolic inference. A key for the performance of this level is the classification of world states in the form of concepts. This reduces the description complexity of a situation. Argumentation in the form of language, rule-based expert systems, and logic are placed at this level. The majority of the explicit knowledge can be positioned at this level. Examples are safety norms in factories that capture the experiences of former accidents. These norms do not have to be based on one's own experience but can also be transferred from other organizations. Language can explain and justify these norms.

Adapting this level to design, we call it **"Design Rational"**. Symbolic design knowledge is codified as text, figures, symbols, etc. A specific design solution can be discussed by means of linguistic argumentation. This level also includes all the different expression skills of a designer such as visual languages (e.g. UML), (technical) drawing, a specific design terminology, and the use of design software.

In design education, this kind of codified knowledge seems to be relatively easy to transfer. The knowledge is already present in an externalized form—the students 'only' have to read or listen to, learn, and remember it. However, a substantial amount of related prior knowledge or experience is often necessary to fully understand the meaning of the codified concepts. This type of knowledge can be used as the foundation for new design concepts and solutions.

Design teaching based on codified knowledge is a valuable approach, e.g. when accessing information about known design alternatives, characteristics of technologies, or certain steps in the design process. This kind of knowledge can be represented in books, or can be expressed verbally by the teacher.

Transition C↔D

This transition describes the process of generating models and theories about the world. Knowledge from the previous level is being transformed into a framework, model, or theory. By moving downwards from Level D to Level C, a theory adds new concepts to the language.

Adapting this level to design, we talk about **"Theory Formation and Concept Creation"**. This transition describes the process of generating models and theories that might be relevant for the designer. Such models and theories could be influenced by e.g. user observations, a system analysis, or storytelling. Designers themselves normally don't create general design 'rules' but rather practical models or frameworks intended for a specific design problem. Such design models could be causal graphs, 'journeys' that describe a process over time, 'two-by-two' matrices, Venn diagrams that classify observations, or fictitious 'personas.'

Within teaching, the Transition C↔D is about understanding complex systems and creating new models and theories of them. The students need to be creative in two ways: First, by understanding and analyzing complex systems, and second, by compressing and abstracting this knowledge into a design theory. One possible approach might be through qualitative research methods, such as 'Grounded Theory'.

Level D: Scientific Models

At this level the knowledge is represented in mathematical or scientific models or theories of the world. Examples are Maxwell's equations for electromagnetism or an Operations Research model that captures the different consequences of a decision problem.

Adapting this level to design, we call it **"Design Theories."** Within this level design knowledge is represented as (testable) theories and models. These theories are often created by someone else, and are adopted to form the basis of new and different solutions. Typical models in the design area are design theories (e.g. Codd's (1970) relational database model), ergonomic norms, or patents, which can be adapted for specific purposes. Different design solutions according to one theory or model can later be tested and verified (e.g. a chair which was designed, based on ergonomic norms, can be tested with a number of test persons that represent a sample of the population's body masses). Alexander et al. (1977) introduced a set of patterns that are applicable on different design problems. Simon (1996: p 113) argues that we need a science of design that is a "tough, analytic, partly formalizable, partly empirical, teachable doctrine." Compared to a natural or behavioral theory, a design theory focuses on "how to do something," and gives "explicit prescriptions on how to design and develop an artifact" (Gregor and Jones, 2007: p 313).

Knowledge in level D is also present in an externalized and codified form, which makes it quite easy to transfer within design education. However, this type of knowledge is more complex, since it often requires greater prior knowledge and provides insight about a complex system in a very compressed form, and thus requires greater sophistication for a student to understand it, and of the teacher as well, who needs to explain it verbally.

Prioritizing of Levels

The four levels of design knowledge are materially building-up on each other, because each level requires the existence of the lower levels. However, we would like to emphasize that we do not suggest any priority of these levels. Each type of knowledge has its specific characteristics and strengths. Each level can work fine without the higher levels, but not without the preceding lower levels.

LITERATURE REVIEW FOR DESIGN KNOWLEDGE

Before developing the aforementioned framework of design knowledge, we conducted an extensive literature research on existing theories and models about design-specific knowledge. In order to compare the analyzed scientific sources with our framework, we place the literature review after the introduction of the framework itself. In Table 2 the results of the literature review are shown. We focused on design knowledge taxonomies or classifications, and disregarded work that just used existing design knowledge categories (e.g. in empirical protocol analyses).

Cross (2001; 2006) distinguishes between three main categories of design knowledge: knowledge of people (outstanding designers), knowledge in design processes, and knowledge that lies in design artifacts. We can match these categories partly with our framework: Knowledge within artifacts is in line with Level A of our framework. Knowledge that lies within people can either be explicit, as long as the person is able to verbalize his or her knowledge (Level C), otherwise it is implicit knowledge (Level B). Moreover the knowledge of such an outstanding designer might be represented in his/her work, which makes it also viable to place this kind of knowledge on Level A—embodied in their artifacts. Knowledge in processes is usually a sequence of steps, to ”do this before that“, and is therefore codified knowledge and can be placed in Level C. If the process is tacit knowledge it could also be Level B. Cross (2001) also mentioned the importance of reflecting upon design activities (Transition B↔C), which is in line with Schön (1983).

Dorst and Reymen (2004) and Dorst (2003a) present a framework for design expertise, consisting of levels of novice designer, advanced beginner, and competent designer, as well as the transitions between those levels. While our framework focuses on different forms of knowledge that are not necessarily correlating with a certain level of expertise or experience of a designer. The framework presented by Dorst offers some interesting links: his findings indicate that the novice designer is more reliant on rules and facts (Level C), while the advanced beginner reflects upon which rule might fit to which purpose (Transition B↔C). The competent designer, in contrast, acts according to trial-and-error (B), while expert designers rely even more on intuition in their responses to specific situations (B). This seems to be a very promising direction for further research.

Heylighen et al. (1999) distinguish between passive knowledge (technical–rational knowledge, Level C) and active knowing (practical cognition, Level B). They emphasize the importance of language and reflection (B↔C) and the interaction of passive and active knowledge.

Uluoğlu (2000) focuses on the design knowledge communicated in critiques. She distinguishes between general (objective, Level C) and personal (subjective, Level B) knowledge. She develops different categories of communicative knowledge: reflective (B↔C), operative (“how to do”, in this case Level C), contemplative, directive, and associative (mainly Level B) knowledge.

Narváez (2000) distinguishes between empirical-analytical (Level C and D), hermeneutical-historical (understanding and interpreting historical phenomena, Level C) and socio-critical (Level C) knowledge.

Most of the analyzed papers do mention one or more of our suggested types of knowledge representation, using different names, however. There seems to be a common understanding of the two types tacit and explicit knowledge (Level B and C of our framework), even if these are referred to by different names.

Level A knowledge is referred to by some of the papers (Cross, 1999; 2004; Cross, 2006; Lawson, 2004; Schön, 1988; Zdrahal, 2007) as “embodied knowledge”, “knowledge in products and artifacts”, or “precedents.”

Until recently, Level D knowledge was rarely defined. Dorst and Reymen (2004) mention the necessity of testable knowledge, but do not specify what that might be. Narváez (2000) refers to empirical-analytical knowledge. Gregor and Jones (2007) describe the components of a design theory.

The analyzed papers rarely pick up the transitions between the different kinds of knowledge. Schön (1988), Heylighen et al. (1999), Cross (2001) and Dorst (2003b) mention the importance of reflecting upon the results of trial-and-error (B↔C). Schön and Wiggins (1992) emphasize the importance of "a particular way of seeing" for design. Also Lawson (2004: p 3) mentioned the ability „to see or hear in particular ways". This could be interpreted as the transition between the physical level and tacit knowledge (A↔B), in which one's perception or filtering is being adjusted. The inability to specify this phenomenon in a structured way indicates that there might be a need for a structured framework of design knowledge, as we have presented. Also the fact that some papers defined types of knowledge that can be placed on more than one level of our framework—which means that it could function in totally different ways—indicates the necessity of such a structured common framework.

We found four concepts that are orthogonal to our framework. The first concept is the level of expertise (Dorst and Reymen, 2004), which is applicable for all levels of knowledge representation. The second is the level of diffusion of the design knowledge. Bertola and Teixeira's (2003) differentiate between user's, organization's, and network knowledge. Because our framework analyzes knowledge representation in all systems it is also able to analyze individual as well as organizational knowledge. The third concept is the generalizability of the design knowledge. Situated knowledge (Ashton, 2007) is specific to a context or situation and not necessarily transferable to other situations. The fourth concept is the content of design knowledge (knowledge about artifacts, realization processes, and design processes). Van Aken (2005) distinguishes between object knowledge (knowledge about properties of the artifacts and technologies), realization knowledge (knowledge about the processes to realize artifacts), and process knowledge (knowledge about the design processes to produce object or realization designs). Object knowledge and realization knowledge is similar to the concepts of "know-what" and „know-how" of Ryle (1949). All three types of knowledge content could be represented in design artifacts (Level A), tacit (Level B), explicit (Level C), or as testable theories (Level D).

Source	Description	A	A↔B	B	B↔C	C	C↔D	D
(Cross, 1999)	Design knowledge in people (B and C), in processes (C and B), and in products (A)	x		x		x		
(Lawson, 2004)	Emphasizes on knowledge within design drawings (C) and in conversations (C), and also refers to „body-knowledge" or „knowledge in action" (B) and reproducible „precedents" (copying artifacts, A). Ability „to see or hear in particular ways" (A↔B)	x	x	x		x		
(Cross, 2001)	Differentiates between knowledge inherent in the activity of designing (B and C), through reflecting on that activity (B↔C); knowledge inherent in artifacts (A), knowledge inherent in the processes of manufacturing (C and B)	x		x	x	x		
(Zdrahal, 2007)	Focuses on domain knowledge (C and B) as part of process knowledge, experience knowledge (mainly B), and adaptation of precedent cases (A or C depending on complexity). Introduces "Clockwork Knowledge Manager" for managing knowledge in form of text, diagrams, drawings etc. (C)	x		x		x		
(Schön, 1988)	Differentiates between tacit knowledge (B) and explicit knowledge (C). Emphasizes reflection on practice (B↔C). Mentions adaptation of precedent cases (A or C depending on complexity)	x		x	x	x		
(Schön and Wiggins, 1992)	Emphasize on "a particular way of seeing" (A↔B) and reflection (B↔C). Differentiate between intuition (B) and explicit knowledge (C).		x	x	x	x		

(Dorst, 2003b: Chapter Education),	Focus of design education on „learning-by-doing“ (B); emphasizes on the relevance of „reflection“ of the results from B (B↔C); differentiates between talent and implicit knowledge (B), and lectures and skill-related exercises (C)			x	x	x		
(Heylighen et al., 1999)	Distinguish between passive knowledge (C), active knowing (B) and reflection (B↔C)			x	x	x		
(Uluoğlu, 2000)	Distinguishes between general (objective, C) and personal (subjective, B) knowledge. Communicative knowledge categories: reflective (B↔C), operative (mainly C), contemplative, directive, and associative (mainly B)			x	x	x		
(Narváez, 2000)	Distinguishes between empirical-analytical (Level C and D), hermeneutical-historical (understanding and interpreting historical phenomena, Level C) and socio-critical (Level C) knowledge					x		x
(Ashton, 2007)	Mentions explicit knowledge (C) and tacit knowledge (B). Mentions „situated knowledge“ (low generalizability to other context), which is orthogonal to our framework			x		x		
		Generalizability						
(Dorst, 2003a)	Differentiates between trial-and-error (B), rules and facts (C), and intuitive reactions (B)			x		x		
(Dorst and Reymen, 2004)	Differentiate between skill acquisition (B and C), declarative knowledge (C), experiences (mainly B). Need for testable knowledge (D). Levels of expertise, which is orthogonal to our framework			x		x		x
		Levels of expertise						
(Manzini, 2009)	Defines design knowledge as a collection of cognitive artifacts and claims that it should be explicit (C)					x		
(Van Aken, 2005)	Differentiates between object knowledge (properties of artifacts and materials), realization knowledge (physical processes to realize artifacts), and process knowledge (characteristics of design processes to produce object or realization designs), all 3 categories are orthogonal to our framework	Content of design knowledge: Knowledge about artifacts, realization processes and design processes						
(Bertola and Teixeira, 2003)	Differentiate between knowledge embedded in users, organizations, and networks, which is orthogonal to our framework	Diffusion						
(Gregor and Jones, 2007)	Describe 8 components of a design theory (D): purpose and scope, constructs, principles of form and function, artifact mutability, testable propositions, justificatory knowledge (kernel theories), principles of implementation, and an expository instantiation							x

Table 2: Overview of Literature Research

CONCLUSION

Summary and Contribution

This paper is a typology of design knowledge or a "theory for analyzing" (Type I Theory) according to Gregor (2006).

We have developed a framework with four different levels of design knowledge—represented as design artifacts, design intuition, design rational, and design theories—as well as the three transitions between these levels. This framework is based upon a framework for general knowledge processing by Radermacher (1996), which we adapted to the specific properties of design knowledge. We then tried to demonstrate how each knowledge type could be addressed within design education. Finally, we presented a literature review of related work, which indicates the necessity of a comprehensive framework of design knowledge. We believe that the paper contributes to a better understanding of design knowledge and offers teachers and design practitioners a framework for analyzing their own teaching methods and adjusting them, if necessary.

Since the different types of knowledge representation are an important factor in design processes, it might also be important to address these levels differently, when e.g. designing IT-applications to support the design process.

To the best of our knowledge such a structured framework about design knowledge and its representations has not yet been developed.

Further Research

We consider the suggested framework of design knowledge a starting point for further research. As the next step we would like to conduct an extensive case study with a detailed analysis of used exercises and projects for teaching design in different organizations according to the used knowledge types. It might also be interesting to empirically analyze the use of the different knowledge representations within one organization over a specific period of time, or in different organizations with a different focus. We would like to examine whether design experts and teachers tend to use one kind of knowledge representation more often than others, or if there is a correlation between the progress of a project or study and the presence of specific forms of knowledge representation. Based on this analysis, we would like to develop a set of knowledge-specific exercises for design education, including suggestions for new exercises that focus on the different levels and transitions.

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