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INVESTIGATIONS INTO THE DATA BASIS OF DESIGN KNOWLEDGE IN INDUSTRIAL DESIGN ENGINEERING

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Keywords: engineering knowledge, design knowledge, knowledge differentiation

1. Article content and its place within the research field of design knowledge

This article's main topic is design knowledge[1]. It is questioned how design knowledge can be distinguished in opposite to engineering knowledge and what is the specific about design knowledge. Design knowledge refers to a specific expertise of a professional designer. We derive the meaning of design knowledge from the general term, knowledge, and use this relationship for further delineation (see Figure 1). We will also introduce design knowledge in the following three cases, in each of which the emphasis lies on what is known as **data knowledge**.

1. A comparison between the knowledge taught to construction engineers and to industrial or product designers, the two most important partners in the development of technical products and processes. Currently, there exists a conflict between the two fields, caused by their paradigmatically different goals and interests during product development. We assume that a further reason for this conflict is the lack of knowledge about the other party's knowledge. We see opportunities for a reciprocal exchange of knowledge in the current discussion in the engineering sciences about methodology (FELDHUSEN/SCHLUZ 2007; HEYMANN 2005).
2. An interpretation of the evaluation categories for design awards and competitions according to a theoretical model of the memory system's content (see Chapter 2 of this article).
3. Description of an experimental approach to investigate the content of data knowledge as a subset of design knowledge and a depiction of results to date.

The topic of this article can be incorporated into the current scientific discussion about design knowledge, e.g. by VISSER (1995), LAWSON (2004), CROSS (2006), CARVALLHO/DONG (2007), AHMED (2007), and others. We intend to expand on existing theoretical models of design knowledge. The models of knowledge and memory for the neurosciences and psychology serve as the basis for this expansion and make a formal description of knowledge and mnemonic processes possible. At times, we can generalise the concrete assertions of these models. In this article, we will describe a **construct for a theoretical schema** that will build the theoretical groundwork for further study and will serve as a communicative aid.

[1]The term design is a comprehensive one and should be clarified briefly. In this article, when we use the term design, especially in regard to design knowledge, we are referring primarily to the aspects of its doing. The German word *entwerfen* is a synonym for, but slightly different from the English verb, to design, and better emphasises this connotation. Design knowledge in this case comprises the knowledge one has or needs to *practice* design, e.g. to conceptualise, sketch, to imagine, to frame problems, propose solutions, etc. Further, when we write "designer" we are not only naming a profession, but "someone designing". Please refer to our design definition on p.2.

But what is knowledge?

Knowledge is everything that a person has at his memory's disposal. Not only is that what is commonly understood as knowledge and what one thinks one knows are kept in memory, but also the operation with knowledge's content. The term knowledge comprises all convictions, including false. Knowledge is everything, what a person believes he knows (TALK 1995:53-54). Starting with the general meaning of the term knowledge, we arrive at this article's focus, seen in Figure 1. Design knowledge is linked to general knowledge in that it draws from and contributes to it. Knowledge is more than its colloquial identity, as the operative procedures in the human mind also belong to knowledge. Knowledge is comprised of two fundamental aspects: knowledge about things and their relationships and knowledge about procedures and methods, to which the knowledge about things belongs.

Design knowledge

The term design knowledge in this article can mark a kind of professional knowledge (Fig. 1, see footnote). The knowledge of a lawyer, carpenter or engineer is analogous to professional design knowledge. Professional design knowledge comprises competence and interests beyond the practice of design, e.g. design management, commissioning, contract and copyright knowledge, design organisation or design theory.

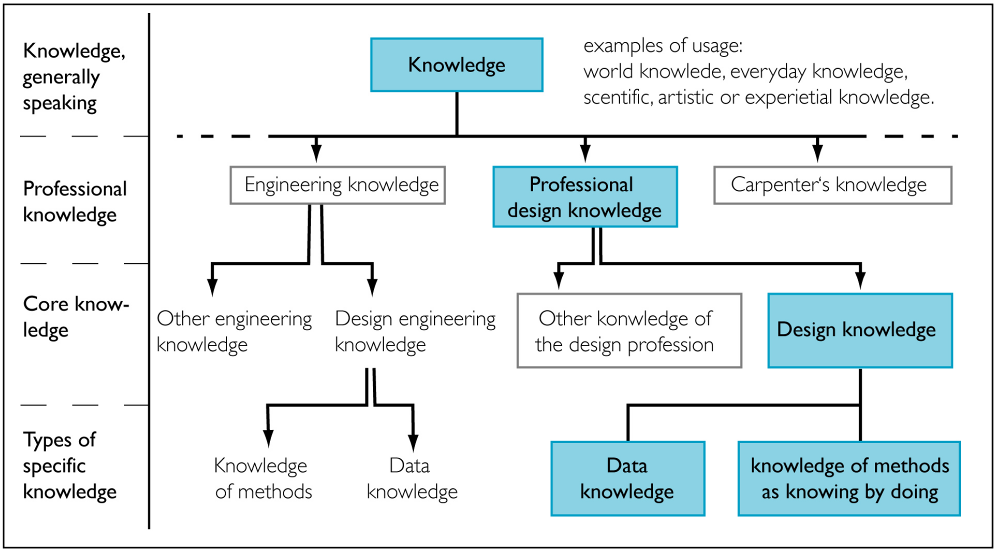

Figure 1. Design knowledge in a hierarchical order of knowledge

According to the underlying general definition of design, design knowledge is the **informational and methodological knowledge** necessary "to conceive of something that either does not yet (in such a form) exist and to visualise it in a manner in which it can be manufactured or further treated" (UHLMANN 2006:27). Design knowledge's subject matters are objects and processes. Industrial design engineering deals mainly with technical objects, e.g. machines, apparatuses or facilities, and their related processes, which can be considered socio-technical systems and handled as such (UHLMANN 1979, 1992, 2005; GIESE 1984; BAARSS 1988). The designated objects of industrial design engineering show that designing is carried out in cooperation with other fields, in particular with engineering sciences.

2. Theoretical schema to explain design knowledge and to classify data knowledge

Design knowledge is lingual knowledge and mainly **non-lingual**, representational, knowledge. Representational knowledge is externalised in **representational modalities of design actions**, e.g. sketching, drawing, physical or virtual modelling and shaping on the object itself (UHLMANN 1986, 1992, 2006). Given the general outline of knowledge (Fig. 1), one can break down design knowledge into two components a) knowledge of things and persons and b) knowledge of procedures, which we will denote **data knowledge** and **method knowledge** (LAUBSCH 1995) respectively.

The term representational knowledge includes lingual represented knowledge and knowledge about objects, buildings, rocks, landscapes, animals, machines, jewellery and persons. The term pictographic knowledge and pictographic thinking can only be used for such objects in a limited way, because the term picture has a narrower meaning. It is the nature of a picture (e.g. in mathematics or in arts), not to be identical with what is pictured.

With it, drawings and sketches are pictures, but not real technical objects or persons. Representational design action means to excogitate an object and to present it. The means of presentation can be a drawing – in this case it is represented to the outside in a pictographic way, or the object itself or an analogue model is used – here sculptures in art or cars in design process are examples. Within representational design action, the internal methods of procedural memory system use non-lingual represented elements of data knowledge within the declarative memory system. Perhaps famous for the topic of non-lingual represented knowledge is the investigation by GÖRNER (1973) about functions of drawings within engineering. A comprehensive paper can be found in Sachse (2002). The scientific state of knowledge about this problem of representational design action is very low, may be because the preferred method of investigation is still lingual representation of knowledge. (For the topic of non-lingual representation of knowledge please refer to ENGLISCH/SACHSE/UHLMANN (2008) within this conference proceedings).

A consistent model capable of depicting both components of design knowledge, data and method knowledge, is necessary for the purpose of our study. Because one could not be found in the traditional sciences, such as psychology and the engineering sciences, we have adjoined two different existing theoretical concepts in Figure 2: the **model of the human body of knowledge's content**, which depicts static knowledge supply, and the **action regulation model**, which describes processes within design activity.

The combination of stationary data knowledge within human long-term memory is depicted in the upper part of Fig. 2 and the dynamical knowledge process within action – here the design action – as a procedure running in time in the lower part.

Within that, knowledge relevant for design within the model of the **human body of knowledge** is applied to the knowledge using and knowledge producing **design activity** through a suggested system of production. Processes of knowledge within design activity differ fundamentally from ways of dascription within the body of knowledge and are accessible though the theory of psychic regulation of goal-orientated actions (HACKER, 2005), which is depicted schematically on the lower part of Fig 2.

According to behavioristic tradition, emotions within cognitive psychology are potentially not always seen as part of all knowledge processes (REIZENSTEIN, MEYER, SCHUETZEWOHL 2003). Therefore they are placed in the middle of Fig. 2 with arrows direction to both models of knowledge

The idea of implicit and explicit knowledge includes the state of conscious availability of knowledge and concern knowledge within both theoretical model displayed in scheme. Therefore implicit and explicit knowledge are also placed in the middle of Fig. 2 with arrows to both models.

Using the model of memory's content (trans. term from MARKOWITSCH, 2005), which is called the model of "the human body of knowledge" (trans. VAN DER MEER, 1998) here, one can depict the entire individual memory of a person, available in his long-term memory in a **quasi-static** and **temporary dormancy**.

According to this model, human knowledge can be further broken down into two fundamental types of memory: the declarative and procedural systems. The community of science agrees upon this classification.

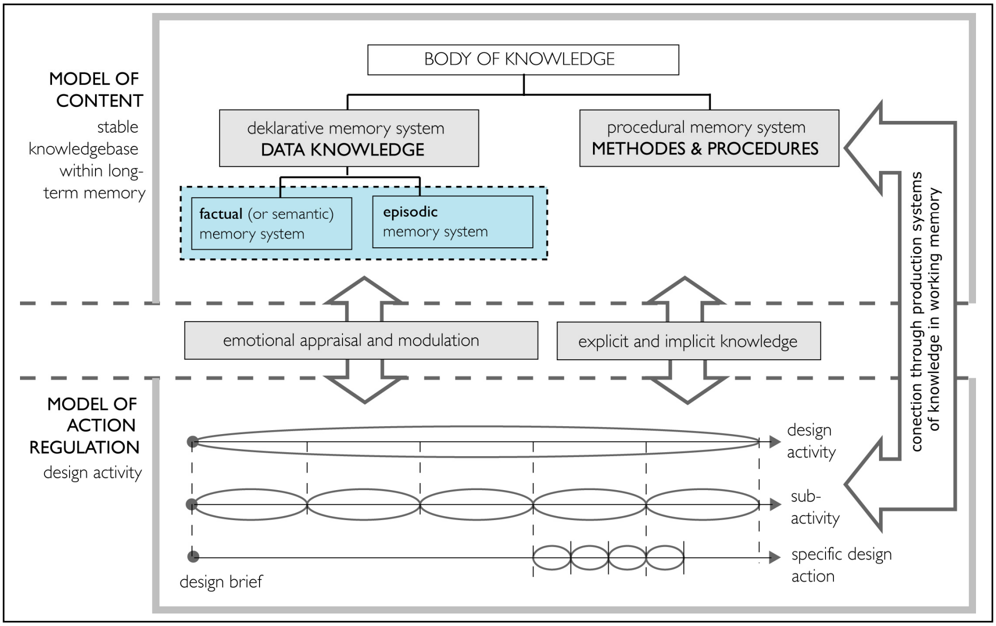

Figure 2. Theoretical schema to explain design knowledge and to classify data knowledge

The **procedural, or method memory**, comprises knowledge about procedure and approach. It is knowing how. These methods must be acquired by one's own doing. Included in it are behavioural routines, but also perceptive and mental routines (BODENBURG, 2201). Put simply, the method memory harbours the routines necessary for designing when one is not engaged in the activity in a kind of dormancy of potential kinetic design capability.

The **data, or declarative, memory** represents the entirety of descriptive knowledge or knowledge of the type "knowing what". Data memory is divided into **factual, or semantic**, memory and **episodic** memory (TULVING, 1972, 1984; MARKOWITSCH, 2005; EYSENCK&KEANE, 2005; ROTHE, 2003; BODENBURG, 2001 and others). These two types of knowledge are represented through different parts of the brain. Episodic memory is located within the hippocampus, the semantic within parts of the adjoined perihinal and entorhinal cortex (MARKOWITSCH, 2005; BODENBURG, 2001)

Factual, or semantic, memory comprises all knowing as we understand it colloquially. Factual knowledge is learned knowledge, and has been attained through instruction and from external sources. It is a knowledge of facts independent of person and contains the general information a person has, including autobiographical data and schooled knowledge (BODENBURG, 2001). This knowledge of fact is socially standardised and as such, a fundament for the knowledge systems of education and natural and engineering sciences. Factual knowledge is objective knowledge or knowledge that can be objectified and therefore can usually be judged as **right (true)** or **false** (also see: OWEN, 1998:16)

Every practicing designer knows that he does only utilise data that he has acquired or learned, but what is shown in the knowledge model as **episodic knowledge**. In more recent literature about design knowledge, LAWSON (2004) goes into the importance of episodic knowledge at the beginning of design work. Looking at results about design knowledge from the theoretical perspective of the model of memory's content one can see that both what VISSER describes as "everyday knowledge" and the knowledge with a "sociocultural reference" in STRICKFADEN (2006) deal with the interdependence of knowledge of both the factual and episodic memory systems.

Episodic memory, so important to design knowledge, is bound to a person's biography and therefore to one's own SELF. It is the memory system of remembering, and in it is data regarding concrete incidents and **temporal-spatial** relationships to one's own person. Episodic knowledge is knowledge that can be **experienced** (BODEBURG, 2001). It is then subjective knowledge that need not be evaluated by objective standards of factual knowledge if it fulfils subjective measures of truth.

The existing dormant knowledge supply can be described with the model of memory's content, however it does not hold for design activity as a temporal part of design knowledge. During design activity, a **conscious goal**, its **motives** and its **intentions**, the latter of which is a conscious act of will, accompany the **static body of knowledge** at decisive moments. The process of designing occurs according to internal deliberate non-impressionable regulatory mechanisms. Data knowledge from the factual and episodic memory is added as regulatory knowledge to the procedures of one's methodic repertoire. Knowledge about methods arise less from instruction (HACKER in REESE, 2005). It is developed through **learning by doing** as knowledge one experiences, in that the designer achieves his result through the interaction of conotive, cognitive and emotive components of his consciousness with the sensorimotor activity of his hands. This knowledge can be characterised as **experiential knowledge** due to the interaction between all components of consciousness in the designer's mind and his executive action.

A large part of the knowledge relevant to designing is so-called tacit or implicit knowledge (STERNBERG, 1995 and WEBER&WEBER, 2001 in HACKER, 2005: 370-371), which differs from explicable, explicit knowledge. Design experts rely heavily upon their tacit knowledge, which can include both their data knowledge and their knowledge of methods (HACKER 2005, and others). This assertion from literature refers to what is **lingualy** explicable and overlooks the fact, that representational design results must be seen as a **complete externalisation** of design knowledge related to the design object.

3. Attaining academic knowledge in industrial and product design and in engineering

We will explore how design knowledge is conveyed in industrial and product design fields in comparison with the key knowledge imparted to engineers. Of the many options available to carry out such a comparison, we have chosen to compare the curricula of the two domains.

Results in KRANKE (2007) about models and proceedings of integration of industrial design into the education of engineers serve as a basis for this investigation into curricula of the industrial and product design field. This is accompanied with random examinations of curricula of german, austrian and swiss universities. The statements about engineering education is based on regulations of faculty agreement for mechanical and process engineering (FTMV) MARQUARDT (2008), which mission is to ensure a uniform standard of education and standardized subjects at german-speaking universities.

Within such a comparison of curricula, it does not make sense to set courses and their contents directly against one another, as the contents are not directly comparable. A comparison is possible only when the material is standardised by knowledge type though their instructional form. In our case, the curricula contents will be compared with one another according to **factual and episodic knowledge** and to their respective instructional form. In design engineering curricula, factual knowledge is characteristically imparted **receptively**. In industrial or product design, **episodic knowledge** in the form of **learning by doing** seems to predominate. Attaining and implementing new factual knowledge is directly integrated into this instructional form. The basis for our comparison are the aims of each field.

The engineer's aims, according to PAHL/BEITZ, are to "…to find solutions to technical problems. The engineer relies on findings of the natural and engineering sciences and takes into consideration material, technological and economic conditions as well as legal, environmental and human factors" (trans. PAHL/BEITZ and others 2003:1). The result of design engineering work is a technical design object, which is the focal point of this activity (Dixon, Penny in PAHL/BEITZ et al. 2003).

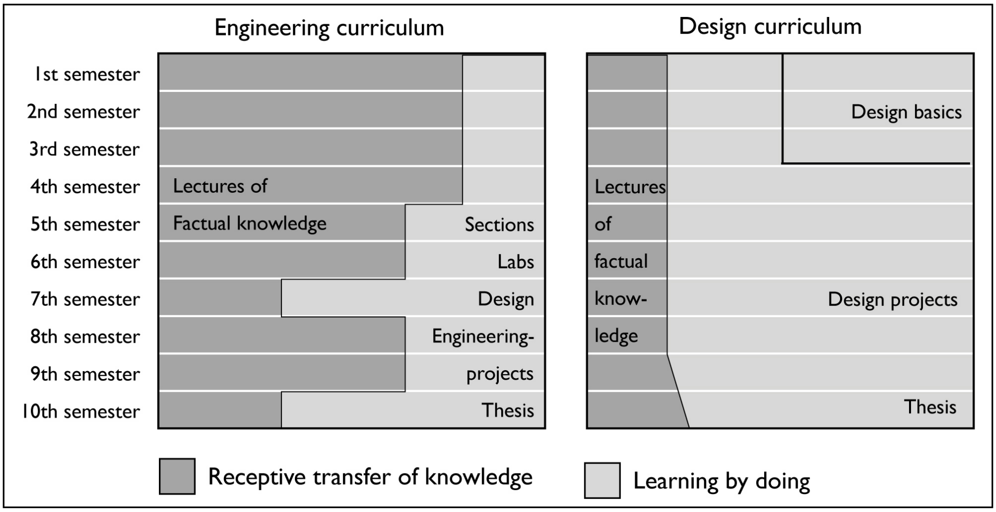

Figure 3. **Comparison of curricula types for a design engineering degree and for an industrial or product design degree**

The education of design engineers is based on courses in mathematical as well as natural and engineering sciences and on the acquisition of particular constructive factual knowledge. The prevailing instructional form is receptive, e.g. through lectures, study and independent use of informational sources. Labs and sections serve to expand the student's understanding of the taught material. Students implement their knowledge independently in internships and project work, and in theses or senior projects. The labs, sections and theses work all correspond to the instructional form of learning by doing, although this form makes up only a small part of the design engineering curriculum (see Fig. 3). Prerequisite factual knowledge for the purposes of higher education is obtained in prior schooling. Evidence of the knowledge one has, aside from the interest in a particular field, is the admission process. According to EHRLENSPIEL (2003:115), the experiences one has as a child with arts and crafts and with the playful occupation with geometry also belong to the scope of factual knowledge that a person brings with him.

The **aim of design** is the **product**, or process, **experience** of its user, on whose behalf an item is designed (UHLMANN 1986, 1992, 2005; HACKER in REESE, 2005)

The German word for **experiencing** ("erleben") is available to express all internal processes of the conscious mind. One speaks of experiencing when reason is joined by emotion. Emotions are not additives to thought; Emotions "are modulators of cognitive and motivational processes and not annexed modules" (trans. DÖRNER 2006). When dealing with targeted activity such as designing, specific knowledge and conscious will are further regulatory components.

Industrial and product design programmes impart knowledge on their students primarily in design projects by way of learning by doing.

Admissions tests are not unusual to design programmes. In addition to fulfilling other enrolment requirements, students are required to submit a portfolio of their work.

The courses in design fundamentals and contents of design projects incorporate students' prior knowledge to a considerable extent. Their skills are those attained through schooling, those related to their biography through interests and hobbies and those that stem from their own doings in the field, e.g. conceptualising, drawing, shaping, etc. Design projects make up the primary didactic form of the major and demand the most time. The specific factual knowledge for each project is obtained as it is needed.

The essence of project work lies in the guiding and correcting development of design methods with the incorporation of data knowledge. The main task of educating students is to expand existing knowledge in combination with reason, motivation, will and emotion when designing. Classes whose factual knowledge is conveyed receptively makes up a small part of the curriculum. This also becomes clear in comparison with the curriculum of a design engineer.

If, according to the model of memory's content, there are two sorts of data knowledge, the major part of the data knowledge in industrial and product design curricula must be episodic knowledge.

Differences between the curricula of design engineers and industrial and product design result from the different goals of each field. Interestingly, they both work on the same object. Eliminating this unnecessary conflict belongs to efforts towards integrated product development. One proposal for an interdisciplinary cooperation can be found in *Procedure Planning for the Design Process* (UHLMANN 2005).

4. Evaluating data knowledge in design awards

In design competitions and awards, a product must be fully evaluated. This evaluation takes place according to the predefined criteria of evaluation catalogues. Considering the aspect of knowledge according to the model of memory's content, a complete evaluation, as a summary of the evaluation of single attributes, demands the existence of both kinds of data knowledge in the product. Judging submitted work based on a prototype can be interpreted under the aspect of design knowledge as an embodiment of all the knowledge utilised to create it: procedural and both kinds of data knowledge. The procedural knowledge is dissolved in the result, in that the question of "knowing how" has been answered with the realised product. Both kinds of data knowledge, factual and episodic knowledge, can no longer be separated from another in the material product. The once subjective episodic knowledge has lost its subjectivity as it has become an objective fact. In this manner factual knowledge becomes the carrier for episodic knowledge, in that episodic knowledge modulates the factual knowledge in a similar manner that emotions affect rational thought. Episodic knowledge is therefore equally less additive as emotions are to cognition (see DÖRNER 2006).

The evaluation catalogues for design competitions contain categories sorting the different criteria. To judge a product as objectively as possible, attributes that are not objective have to be standardised so that a jury can issue an objective estimation. The physically technical parameters of products, licensing specifications and budgeting are actual objective aspects that can be evaluated. These criteria are based on accepted valid factual knowledge and can be securely judged as right or wrong. Other categories, e.g. environmental friendliness, practicality, or visualisation of function, are hybrids of objective and subjective values. Categories such as formal quality or symbolic and emotional content are purely subjective in nature. These can be standardised and then judged objectively by the jury, who serves as a substitute for the user.

Such an evaluation about embodied episodic knowledge is an evaluation of **appeal**, in allusion to KANT (1790/1974). An object either appeal or does not appeal to a person. An **aesthetic evaluation** takes place when the aspects of **correctness** are incorporated to form an integrated evaluation (KANT 1790/1974).

	Design award		Classification of evaluation categories according to the predominance of		
	iF Industrie Form	Red dot award	⦿ correctness ☺ appeal	receptive knowledge transfer	Learning by doing
1.	Practical use	Funktionality	⦿	×	
2.	Safety	Durability	⦿	×	
3.	Durability	Ergonomics	⦿☺		
4.	Ergonomics		⦿	×	
5.	Technical and formal autonomy	Degree of Innovation	⦿☺	×	×
6.	Product periphery	Product periphery	⦿☺	×	
7.	Environmental friendliness	Ecological compatibility	⦿	×	
8.	Visualisation of use	Self-explanatory quality	⦿☺		×
9.	Formal quality	Formal quality	☺		×
10.	Sensory and mental stimulation	Symbolic and emotional content	☺		×

Figure 4. Evaluation categories for design awards and their classification according to correctness and appeal as well as to the predominant form of knowledge transfer (HAASE and BILLER 2002:72-76)

5. Experimental studies differentiating factual and episodic knowledge in the data basis of design knowledge in industrial design engineering

The aim of our study, some of whose features are portrayed below, is to develop a suitable analytical instrument that can strictly and assuredly differentiate the two kinds of data knowledge, factual and episodic. With this instrument, it should be possible to better understand the distribution of mnemonic content in the beginning phases of design problems. Both types of data knowledge determine the methods used in the design process from the very start and thus the result. There are not yet efficient ways to determine the proportions of both knowledge types (factual and episodic) in the phase “clarifying the task”, or “problem-framing”, at the start of the design process according to the procedure plan (UHLMANN 2005). This is a particularly relevant problem in the teaching of students enrolled in industrial design engineering at the Technische Universität Dresden. Their curriculum contains industrial and product design subjects in combination with mechanical design engineering courses. When faced with design tasks whose goal must be found by defining a design concept, the novices tend to rely on the secure factual knowledge from their engineering work, rather than use their personal experience. Analysing the design knowledge in language should help make a person’s own knowledge more accessible so that he can better control and optimise it when designing.

On the basis of the model of the human body of knowledge introduced in the previous chapters, a detailed catalogue of criteria contrasting specific properties of factual and episodic knowledge was drawn together. In order to test the ability of this catalogue to differentiate knowledge, we conducted a preliminary study, in which we checked text material that would presumably show differing percentages of each kind of knowledge: we found predominantly factual knowledge in patent texts and in scientific articles, and largely episodic knowledge from a written description of a drawing and an interview.

An explorative set of studies with short design tasks was conducted in order to differentiate the two knowledge types in the way they are externalised in the design process. The conditions of the studies were adapted selectively in relationship to the findings. The set of studies had a **repetitive** and **conceptual** drawing task at its core. The repetitive drawing task was to draw an object assumed to be familiar to the test persons, an axe, from memory. The second task was to create a Ferrari axe, an object that does not exist.

The task required the transformation of verbal code (the assignment) into pictorial code (the result). Access to the knowledge used to complete the task seemed simplest through lingual coding forms. This is a legitimate approach considering that we are not interested in the distribution of the knowledge types in coding forms of representational design action, such as in the drawing of images, but the distribution between factual and episodic knowledge independent of their respective form of coding.

At the start of the repetitive drawing experiment, the test person is told to draw an axe with the instructions “Please draw an axe. You have fifteen minutes. Should you finish ahead of time, simply stop.” For the collection of analysable lingual data, retrospective interviews in a semi-structured form with standardised opening questions have proved more successful than the method thinking out loud. These interviews were audio-recorded. For the continuation of our study, we plan to utilise video recordings of the experiments that can be used to support the subsequent interview.

The design task to create a Ferrari-axe differs from the repetitive drawing task largely in its demand to creatively interpret this synthetic phrase through one of the modalities of representational design action, drawing. The instructions for this task are as similarly economical as those for the repetitive task. The test persons were conceded approximately 90 minutes, which could be exceeded or cut short. The single fixed condition was that the work was not to be interrupted.

Data collection and analysis

For the repetitive task, one to three sketched pages were produced.

The average duration of the subsequent interviews was seven minutes (3:17-10:50 min.)

For the design exercise, two to seven sketched pages were produced.

The average duration of the subsequent interviews was 10:40 minutes (7:26- 15:00 min.)

All pictorial material was scanned and all verbal material was transcribed. When possible, incomplete sentences were completed in the context of the question posed.

For the analysis of the data, we cooperated with the field of applied linguistics. At the moment, suitable instruments for analysis are in development. Initially we developed analysis categories according to MAYRING’s content (2003) and to KINSTCH’s proposition analysis (1998). In both of these methods, a spoken statement is reduced to its quintessence, which can then be abstracted in regard to the question posed. In this manner, categories emerge from the text and can then be structured.

The following criteria – still highly hypothetical – were developed from random samples of transcribed interview material (Fig. 5: next page).
After an initial hypothesis about the analysis of the data, we can identify “personal memory (SB-E)” as an “event-specific episode from personal past”, as previously done by VISSER (1995) from the Delft Protocol Workshop. Further, it seems that the categories “personal appraisal of the design task (SB-Wa), “defined intention (HZ-Z)”, and “hypothetical scenario (SZ)” can be found in the entire interview material. These categories may show a connection to episodic knowledge.

The above depicted coding scheme of categories is an initial result of the analysis of the interviews from the explorative study. The system itself is first draft that is now being tested. We are looking to create more detailed criteria. To verify these criteria, we will also need to increase the quantity of data.

These studies have been carried out with individual industrial design engineering students at TU Dresden in laboratory setting. We will continue these. Additional test persons will be mechanical design engineering students and students of other technical fields, as well as students majoring in transportation design. We expect to find a higher percentage of episodic knowledge determining procedure especially at the start of new design projects in the latter group of test persons. Especially interesting are the planned experiments with persons who have less experience with design tasks as they are understood here.

category	name	description
personal (SB)	personal memory (SB-E)	description of ones own past
	personal state (SB-Z)	personal state of experience and knowledge
	personal appraisal (SB-W)	(SB-Wa) personal appraisal of the design task
		(SB-Wo) personal appraisal of the design object
scenario (SZ)	hypothetical scenario (SZ)	a story (impersonal, general), description of an imagination, possibly an mental image
object description (OZ)	object description (OZ-S)	
	functional description (OZ-F)	
action description (HZ)	defined intension (HZ-Z)	(want, may, should)
	association (HZ-A)	phrases, fragments, thougth origins
	action within design process (HZ-E)	description of action

Figure 5. Categories developed from the interview material in order to separate the underlying knowledge base of design knowledge

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