



pared diaries and retrospective descriptions of their design processes, collected notes and sketches with timestamps. In addition, these students have been observed and interviewed. The investigation has shown that some students have difficulties gaining knowledge at the start of the design process. One reason for this could be the uncertainty that novices feel at the beginning of design processes. Design problems are wicked problems: the goal as well as the path leading to it is not known at the start. This causes wide room for goal setting and realization.

Designing requires knowledge. Some novices mistakenly start the design process with an extensive knowledge acquisition from external sources. But the source of the larger part of knowledge used in the design process is the designer himself [Goel 1995]. He must however be able to activate and use this source. We aim to provide methods, which help novices to start knowledge acquisition in their own archive. In doing so, two aspects play a central role. First, the designer's attention must be focused on the knowledge, which is important for the design process. Second, the problem must be simplified to a manageable wickedness.

In this paper, we will define design knowledge in the sense of the problem stated above. We will describe two studies, which follow different approaches to supporting the acquisition of design knowledge. The first study investigates the achievement of training about handling knowledge for design students. The second study investigates the impact of developing and analyzing narrative scenarios of usage and prototypical users by certain methods. We will discuss problems in analyzing the effect of the methods and possible solutions.

## 2. A Definition of Design Knowledge

There is a broad debate about the term design knowledge in the recent time. It concerns function, structure and content of design knowledge. The term design knowledge is fuzzy and comprises different applications. In order to be able to select and develop methods we need to define the term for our purposes. Our definition of design knowledge is built upon elements and definitions of diverse

scientific disciplines. Overlappings, inconsistencies and some contradictions of terms and contents that occur will not be discussed in this paper.

The goal is not known at the start of the design process. Due to the fact that it must be anticipated, we can ascertain from the categorisation of design knowledge according to Van Aken [2005] that the above-mentioned activation problem deals primarily with *prescriptive object knowledge*. From here on we will use the term design knowledge to mean this subset.

Jonas [2004] describes *not-knowing* in the design process. At the start of a design process, the designer knows almost nothing about the goal. He knows just as little about the path leading to it. Notions about the process, the environment and implementation of the design object do exist, but these are neither precise nor verifiable [Lawson 2006 and others].

Design knowledge is *prior knowledge*. Phases of systematic and opportunistic behaviour alternate while designing. During opportunistic phases, the designer recalls previous tasks or problems that he has solved in a certain manner and applies them to the problem at hand, even in cases in which a systematic approach might lead to another, possibly better solution [Hacker & Sachse 2006]. (Unconscious) use of prior knowledge can be observed in many disciplines [Schön 1983], and studies show that it is inevitable [von der Weth 1994 and others]. In contrast to the field of engineering, design cultivates this behaviour [p. e. Cross 2003, Lawson 2004, Dixon/O'Reilly 2004].

Design knowledge is *tacit knowledge*. Design knowledge, for the large part, is knowledge that exists but cannot be expressed in words. According to Polanyi [1966] this tacit, or implicit knowledge, cannot be converted into explicit knowledge. However, tacit (design) knowledge can serve as the basis for generating explicit (design) knowledge [Nonaka & Takeuchi 1995, Rust 2004].

Design knowledge is *episodic knowledge*. The knowledge used by designers can be divided into neuro-scientific knowledge categories

[summarised e. g. by Uhlmann & Schulze 2007]. During the design process each of these categories of knowledge is used, but at the start the focus lies on declarative knowledge, including its factual and episodic knowledges. In industrial design, episodic knowledge plays a very important role [Lawson 2004, Uhlmann & Schulze 2007 and others]. The same has been proven for engineering disciplines [Visser 1995, von der Weth 2001].

Many studies suggest that design knowledge is *everyday knowledge* [Lawson 2004, Visser 2006, Uhlmann & Schulze 2007 and others], i. e. it is not solely knowledge gained from education or work, but from the entire day-to-day life of the designer. Many tangible and intangible socio-cultural references contribute to the design process [Strickfaden 2006].

Design knowledge is *objective, subjective and emotional knowledge*. Design knowledge concerns experiencing. In contrast to design engineering, design focuses on the experiential relationship between the design object and the user. This experience is an individual one, and the evaluation of the object tends to be holistic. These judgements include objective as well as subjective and emotional criteria, even for the object's technical functions. Experiencing, subsuming many names, traditionally belongs to research about design methodology and has recently been given more attention [p. e. Press et al. 2003, Budd et al. 2003, Uhlmann 2005].

From the descriptions and definitions listed above, we conclude the following attributes of design knowledge:

- It is not known at the very beginning of the design process
- It must be acquired from the
  - prior (and experiential) knowledge
  - episodic and factual knowledge
  - socio-cultural and everyday knowledge
- It is implicit and tacit
- It is objective, subjective and emotional.

### 3. Application to Empirical Research

This description of design knowledge can serve as a guide for the selection and development of strategies and methods, which support

dealing with knowledge in the design process. This has been and will be done in two studies.

The first study investigates the implementation of certain strategies of handling knowledge according to Reinmann-Rothmeier and Mandl [2000] at the start and during the whole design process. This incorporates for example goal and time analysis, methods for knowledge identification, development and evaluation. This is done for example by using “W“-questions, analogy methods or mind maps for visualization. In addition to that, the participants learn to use the Question-Answering-Technique [Winkelmann et al. 2003] and principles of the task-oriented information exchange [according to Neubert & Tomczyk 1986].

The second study investigates the impact of the development and analysis of narrative scenarios [Steinmüller & Schulz-Montag 2003, Gassner & Steinmüller 2006], which focus on the relations between users and the object to be designed. This set of methods is directly applied at the start of the design process. It can be used by individuals or teams and incorporates rather simple brainwriting and brainstorming methods on topics concerning target groups and users experiencing the product and as its core the development and analysis of narrative scenarios about prototypal representatives of target groups experiencing and using the product to be designed.

Whether such methods are successfully applied in the design process or not depends not only on the subjective advantage of the designer. Soft criteria like contentedness or acceptability are one requirement for the success of such methods. However, the impact must be proven by hard criteria (e. g. time saving, improved solutions, better cost-benefit ratio), being stronger arguments for a broad application of such methods in education or practice.

In literature, diverse strategies for the assessment of design solutions have been described:

- Using task-specific criteria: e. g. Römer [2001], Atman, Cardella, Turns & Adams [2005]
- Comparison to a reference solution: e. g. Wandke & Graf [2005]
- Using criteria not specific to the task: e. g. Meijer [2006].

The first and the second approach require the awareness of all possible solutions, which is impossible in industrial design. Below, we will discuss the difficulties of the assessment of design solutions currently explored in two design research studies.

#### 4. Study 1: Training for Handling Knowledge in Industrial Design

##### 4.1 Research Question

In the first study, we focus on training for handling design knowledge. The participants will learn strategies for dealing with design knowledge, which should be applied especially during the clarification of the task at the start of the design process.

These strategies can also be applied later on in the design process whenever it comes to the acquisition, development and the structuring of knowledge. The training concentrates on identifying and mapping design knowledge as completely as possible at the start of the design process. The knowledge acquired from the designer's own declarative and especially episodic memory is then used as a basis for goal setting and concept development at the beginning of the actual designing. Relevant questions and hypotheses for this paper are:

Does the training for handling knowledge in industrial design affect the quality of design solutions?

- Hypothesis 1.1: Solutions created by designers who attended the training achieve better expert assessments than solutions the same designers created before the training
- Hypothesis 1.2: Solutions created by designers who attended the training achieve better expert assessments than solutions created by designers in the control group who did not attend the training.

Additionally, the participant's acceptance of the training as well as their increase knowledge has been tested.

##### 4.2 Research Methods

The study has been planned and carried out as quasi experiment. A total of 13 students of industrial design engineering participated in the study. The design of the study is shown in Figure 1 [Fig. 1 ↪ 297].

The impact of the training will be tested using the evaluation model of Kirkpatrick [1998]. In this paper we only refer to the transfer level of that model. To be able to reveal the impact of the training success at the transfer level, the test persons tackled different design tasks before and after the training. In order to get comparable results, the assessment of the solutions had to be carried out task-unspecific.

In cooperation with experts we developed an evaluation scheme incorporating the following criteria: creativity, aesthetics (overall, syntactic and semantics), ergonomics, functionality, technical and economic feasibility and overall impression. The assessment scale ranges from 1 being "very good" to 6 being "unsatisfactory". Few design solutions have then been assessed by three experts testing this scheme. The data of the assessments of the different experts revealed only little correlation and thus could not be taken as appropriate for this study. As a result, three other experts with similar work experience had been given more precise instructions for test assessment of a few design solutions. After that, these experts consecutively assessed all design solutions of the study.

##### 4.3 Results

In order to prove the reliability of the scheme, the correlation of the experts has been calculated using the Intraclass Correlation Coefficient (ICC). The ICC not only considers the tendency of correlation but also the mean level of the variables, hence it can be used to value the reliability of the assessments. The ICC ranges from -1 to 1, usually 0.7 and more stands for good reliability [Greve & Wentura 1997]. 0 signifies no correlation. Reliability can not be estimated from negative ICCs and are therefore set to 0 [Wirtz & Caspar 2002].

In this study, ICCs for each criterion of the assessments of each expert have been calculated. Already the mean values of the assessors per criterion and per date of measure vary significantly in 21 of 27 cases. In the best case, the ICC is 0.52 ( $p=0.001$ ), calculated for the creativity criterion in the pre test. As explained above, this does not stand for good reliability. Reliabilities of all other criteria must be rated 0 or are only slightly above zero. Figure 2 shows the creativity criterion of the pre test assessments [Fig. 2 ↪ 297].

Because the reliability of the expert assessments could not be proven, differences between the test and control group have then been calculated separately for each expert to verify the hypotheses according to the following formula:

$$\frac{\mu_{1tg} + \mu_{2tg}}{2} - \mu_{0tg} > \frac{\mu_{1cg} + \mu_{2cg}}{2} - \mu_{0cg}$$

0; 1; 2 ...time (0=pre test; 1=post test; 2=follow up test)

tg ...training group / cg ... controll group

Additionally, differences have been calculated based on the mean values of the assessments. Figure 3 shows the results for the criteria creativity, functionality and overall impression [Fig. 3 → 298].

For a better understanding, figure 4 shows the mean values of the assessments of all assessors for test and control group on the example of creativity. Differences visible in the graph could not be verified statistically [Fig. 4 → 298].

Further tests investigated the acceptance of the training as well as the increase of knowledge about handling knowledge. The participants appreciated the training and increased their knowledge about handling knowledge in the industrial design process.

## 4.5 Discussion

The impact of the training on handling knowledge in industrial design can only be taken as beneficial if a certain sustainability of the training effects can be proven. This regards the application of the learned methods in design practice. We aimed to prove this by using design tasks in the tests. In order to investigate the effect of continuous application of the methods in everyday design practice, a follow up test has been run, which again comprised design tasks.

Despite exact instructions to the assessors, neither correlating assessments, nor significant improvements of the design solutions could be detected. This leads to the following considerations: The assessment process seems to leave too much room for the assess-ments. Possibly the assessors set different focuses when assessing

for example creativity (e. g. holistic object vs. parts). Therefore criteria must be defined more precisely for future studies.

The explanation of the assessment scheme as well as test assessments, which are not part of the study obviously do not suffice. Additional test assessments should be carried out until there is a rough agreement about the quality of the design solutions. Admittedly, this is very time-consuming.

In addition, the unfavourable number of test persons must be mentioned. Only 13 students could participate, which makes it hard to prove effects statistically. Also, the design tasks must be examined and equalized as far as possible.

The hypotheses of this study could not be proven, which is first of all caused by the applied research methods. Nevertheless the hypotheses do not have to be rejected. A reliable method for the assessment of design solutions must be developed in order to offer a basis for studies investigating the improvement of design processes. In the study described below, we pursue this problem by exploring the impact of the development and analysis of narrative scenarios in the industrial design process.

## 5. Study 2: Narrative Scenarios of Usage and Users

### 5.1 Question

The second study focuses on the start of the design process. Students get support during the clarification of the task before the actual designing begins. They are systematically supported by a set of methods for the development and analysis of narrative scenarios of the users' relation to the object to be designed. The application of these methods, including simple brainwriting and brainstorming among other techniques, will help to focus on user experiencing. They will also simplify the design problems to a manageable wickedness. This should lead to more confidence in the design process and to less goal alterations, saving time which can be better used for the actual designing. The development and analysis of the narrative scenarios should serve as a goal oriented acquisition of knowledge. That

enables the conscious development of design concepts and widely avoids wrong decisions. Clarification of the tasks should be completed faster, thus design concepts can be developed earlier. Furthermore, it can be expected that the time saved will be used to put more effort on the actual designing resulting in improved design solutions. From this, two questions can be derived:

Do students cope better with the clarification of the task when they apply the narrative scenarios?

- Hypothesis 2.1: Students who apply the narrative scenarios alterate their goal less often than students who do not apply the set of methods.
- Hypothesis 2.2: Students who apply the narrative scenarios complete the clarification of the task faster than students who do not apply the set of methods.
- Hypothesis 2.3: Students who apply the narrative scenario are contented than students who do not apply the set of methods.

In addition to that we will inspect whether the narrative scenario has an impact on the quality of the design results. This leads to the following question: Can design results be improved by the application of the narrative scenarios?

- Hypothesis 2.4: Objects designed by students who apply the narrative scenario will get better assessments than objects designed by students who do not apply the set of methods.

## 5.2 Research Methods

The study has been planned and realized in different phases. Overall there have been four pre studies with proband groups from 10 to 25 students of industrial and engineering design. The pre studies have been connected with short time and semester design projects.

Pre studies 1, 2 and 3 were about the transfer of the theoretically derived set of methods into practice focusing on the instructions. Pre studies 3 and 4 helped to further improve the instructions and the procedure of the experiment with a focus on data collection and data quality. The following main study will incorporate a larger number of probands in test and control groups.

The impact of the narrative scenarios will be analyzed in different ways. Soft criteria such as contentedness with the situation, confidence regarding the process, motivation for the work to be done will be measured using questionnaires at measurement points in both test and control group.

Collected data such as notes and sketches, the individual design process documentations drawn up by the probands and additional interviews will be analyzed regarding dates of design concept creations, number of goal redefinitions etc.

The design solutions will be assessed. In doing so, we will try to avoid the methodical problems shown in study 1. The study design will allow task-specific criteria leading to more exact expert assessments. Admittedly, it must be pointed at the long time between the application of the narrative scenarios and the assessments, which causes uncontrollable variables aggravating the interpretation of the impact of the method applied. However, data gathered about the design process can be used to facilitate handling these variables. Furthermore, contents of the narrative scenarios will be tracked in design concepts and solutions. This will be used for additional discussion of the assessments.

## 5.3 Results

Pre tests showed that the communication of the methods to be applied at the start of the design process as well as the data collection have been successfully implemented in design projects. Both contentedness and confidence have been improved. Because of several uncontrollable variables (e.g. differing design tasks), this result does not meet scientific standards yet. There is no statement whether design concepts developed earlier served as a basis until the end of the design process or rather lead to more goal alterations. Also, time savings in the clarification of the task have not been proven yet. First statements about this are expected from the last pre study. In order to gain results meeting scientific standards, a main study incorporating a larger number of test persons in test and control groups will be carried out.

## 6. Conclusion

This paper is aimed at explaining a detailed definition of design knowledge, which then has been used as a basis for the selection and development of methods supporting novice designers in handling knowledge within the industrial design process. Presenting two empirical studies on the application of supporting methods in different stages of the design process, we discussed problems occurring in proving the effect of these methods.

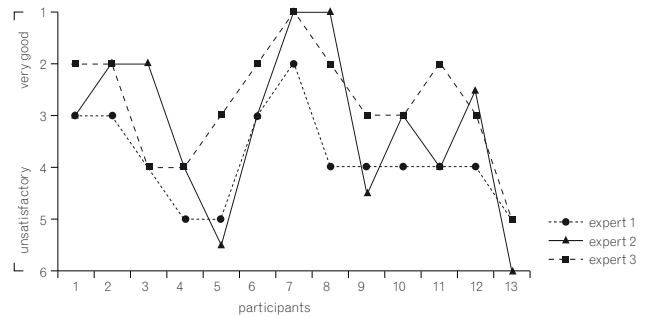
In the first study, we presented the investigation of the transfer level, being only an excerpt of the research. The improvement of design solutions by the application of the training could not be proven. The main reason lies in methodical problems with getting reliable assessments of design solutions. After a revision of the assessment process and the content of the training further tests will be carried out in order to investigate the impact of the training.

In study 2, we tried to avoid the methodical problems described above. The application of narrative scenarios at the start of the design process allows different research methods. The advantage of task-specific criteria for the assessment of design solutions counteracts the disadvantage of a larger number of uncontrollable variables occurring between the application of the methods and the assessment. According to the research problem described in the paper, confidence and contentedness of the test persons have been evaluated. These central but soft criteria have been supplemented with hard criteria such as time saving at the beginning of the design process. Final results can not be derived from the current state of work.

Both studies are part of larger research programs and will be pursued. Apart from the continuing development of supporting methods, an improvement of research methods can be expected.

	pretest	treatment	post test	follow-up test
Q training group	$\bar{Y}_{tg; pre}$	$X_1$ (with training)	$\bar{Y}_{tg; post}$	$\bar{Y}_{tg; follow-up}$
control group	$\bar{Y}_{cg; pre}$	$X_0$ (without training)	$\bar{Y}_{cg; post}$	$\bar{Y}_{cg; follow-up}$

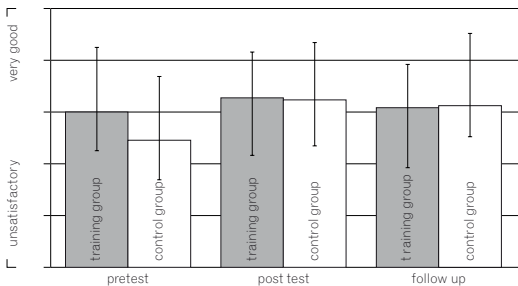
**Fig. 1:** Study design with test group and control group including one pre and two post tests (Y: Quality of the design solutions). I→ 290



**Fig. 2:** Assessments for the criterion "creativity" (pre test) (trans. from Prescher 2008). I→ 291

	expert 1	expert 2	expert 3	mean
	mean difference (p)	mean difference (p)	mean difference (p)	mean difference (p)
<b>creativity</b>	0,6 (0.309)	0,8 (0.250)	0,3 (0.827)	0,5 (0.400)
<b>functionality</b>	-0,1 (0.864)	-0,2 (0.716)	-0,4 (0.493)	-0,4 (0.318)
<b>overall impression</b>	-0,3 (0.546)	0,2 (0.796)	-1,0 (0.145)	-0,4 (0.403)

**Fig. 3:** Results of student's t-test, changes in the mean group performance between pre and follow-up tests. → 292



**Fig. 4:** Mean and standard deviation of the assessments for "creativity". → 292

## References

- Atman, C.J.; Cardella, M.E.; Turns, J. und Adams, R. 2005. Comparing freshman and senior engineering design processes: an in-depth post study. *Design Studies*. 26 (4), S. 325–357
- Budd, J., Taylor, R., Wakkary, R. & Everden, D. 2003. From Industrial Design to Experience Design: Searching for New Common Ground. In *ICSID 2nd Education Conference. Critical Motivations an New Dimensions*. (pp. 137–141). Hannover: iF International Forum Design
- Cross, N. 2003. The Expertise of Exceptional Designers. In N. Cross & E. Edmonds (Eds.). *Expertise in Design*. (pp. 23–35). Sydney: Creativity and Cognition Press, University of Technology.
- Gassner, R. & Steinmüller, K. 2006. Narrative normative Szenarien in der Praxis. In F. E. P. Wilms (Ed.). *Szenariotechnik. Vom Umgang mit der Zukunft*. Bern: Haupt.
- Goel, V. 1995. *Sketches of thought*. Cambridge, Mass.: MIT Press.
- Greve, W. & Wentura, D. 1997. *Wissenschaftliche Beobachtung – Eine Einführung*. Weinheim: Psychologie Verlags Union
- Hacker, W. & Sachse, P. 2006. Entwurfstätigkeiten und ihre psychologischen Unterstützungsmöglichkeiten. In U. Konradt, B. Zimolong & Deutsche Gesellschaft für Psychologie (Eds.). *Wirtschafts-, Organisations- und Arbeitspsychologie: Bd. Bd. 2. Ingenieurpsychologie. (Band 2)*. Göttingen: Hogrefe.
- Jonas, W. 2004. *Mind the gap! – On knowing and not-knowing in design*. Bremen: www.thebasicparadox.de. last visit: 12.10.2007
- Kirkpatrick, D.L. 1998. *Evaluating Training Programs. The four level*. San Francisco: Berret-Koehler Publishers
- Lawson, B. 2004. *What designers know*. Oxford: Elsevier Architectural Press.
- Meijer, M. 2006. Using cognitive conflict in design teams as an asset – Research on the use of cognitive conflict in design teams. Faculty of Industrial Design Engineering, Delft University of Technology.
- Neubert, J. & Tomczyk, R. 1986. *Gruppenverfahren der Arbeitsanalyse und Arbeitsgestaltung*. Berlin: Deutscher Verlag der Wissenschaften
- Nonaka, I. & Takeuchi, H. 1995. *The knowledge-creating company: How Japanese companies create the dynamics of innovation*. New York: Oxford Univ. Press.
- Polanyi, M. 1966. *The tacit dimension*. New York: Anchor Books.
- Prescher, C. 2008. Trainieren von Umgang mit Wissen im Designprozess – Zur Beurteilung von Entwurfsergebnissen. In: Hentsch, N., Kranke, G. & Wölfel, C. (Eds.): *Industriedesign und Ingenieurwissenschaften. Technisches Design in Forschung, Lehre und Praxis*. (pp. 47–56) Dresden: TUDpress Verlag der Wissenschaften
- Press, M. & Cooper, R. 2003. *The design experience: The role of design and designers in the twenty-first century*. Aldershot: Ashgate.
- Reinmann-Rothmeier, G. & Mandl, H. 2000. *Individuelles Wissensmanagement: Strategien für den persönlichen Umgang mit Information und Wissen am Arbeitsplatz*. Bern: Huber
- Römer, A. 2001. *Unterstützung des Design Problem Solving: Einsatz und Nutzen einfacher externer Hilfsmittel in den frühen Phasen des konstruktiven Entwurfsprozesses*. Dissertationsschrift. Technische Universität Dresden. <http://nbn-resolving.de/urn:nbn:de:swb:14-1023713239343-48735>, published 2001, last visit 12.02.2008
- Rust, C. 2004. *Design Enquiry: Tacit Knowledge and Invention in Science*. Design

Issues: history, theory, criticism, 20 (4), 76–85.

↳ Schön, D. A. 1983. The reflective practitioner: How professionals think in action. New York: Basic Books.

↳ Steinhilber, K. & Schulz-Montag, B. 2003. Szenarien: Instrumente für Innovation und Strategiebildung. Essen: Z\_punkt.

↳ Strickfaden, M. 2006. (In)tangibles: Sociocultural references in the design process milieu. Doctoral Thesis, Napier University, Edinburgh

↳ Uhlmann, J. 2005. Die Vorgehensplanung Designprozess für Objekte der Technik: Mit Erläuterungen am Entwurf eines Ultraleichtflugzeuges. Dresden: TUDpress.

↳ Uhlmann, J. & Schulze, E.-E. 2007. Evaluation of design knowledge: empirical studies and application of the results in product design education. ConnectED International Conference on Design Education 2007. Sydney.

↳ van Aken, J. E. 2005. Valid knowledge for the professional design of large and complex design processes. Design Studies, 26 (4), 379–404.

↳ Visser, W. 1995. Use of episodic knowledge and information in design problem solving. Design Studies, 16 (2), 171–187.

↳ Visser, W. 2006. The Cognitive Artifacts of Designing. Mahwah, New Jersey: Lawrence Erlbaum Associates.

↳ von der Weth, R. 1994. Konstruieren: Heuristische Kompetenz, Erfahrung und individuelles Vorgehen. Zeitschrift für Arbeits- und Organisationspsychologie, 38 (12), 102–111.

↳ von der Weth, R. 2001. Management der Komplexität: Ressourcenorientiertes Handeln in der Praxis. Psychologie-Forschung. Bern: Huber.

↳ Wandtke, H. & Graf, N. 2005. Wie können Entwickler beim Entwurf von Assistenzsystemen unterstützt werden? In: Karrer, K.; Steffens, C.; Gauss, B. (Eds.). Beiträge zur Mensch-Maschine-Systemtechnik aus Forschung und Praxis. Festschrift für Klaus-Peter Timpe, Düsseldorf: Symposion Publishing. S. 131–147

↳ Winkelmann, C.; Wetzstein, A.; Dreesen, A. & Hacker, W. 2003. Forschungsprojekt Methodenentwicklung zur Wissensintegration (MIK). Unterstützung der frühen Phasen des konstruktiven Entwurfsprozesses. Fragengestützte Reflexionstechnik (FRT). Projektberichte, Heft 28, TU Dresden

↳ Wirtz, M. & Caspar, F. 2002. Beurteilerübereinstimmung und Beurteilerreliabilität. Göttingen: Hogrefe