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IMPARTING DESIGN METHODS WITH THE STRATEGIES OF EXPERTS

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ABSTRACT
The development of design methods started with the experiences and individual findings of outstanding engineering designers such as Wögerbauer [1], Kesselring [2], and Pahl [3]. They describe their experience and findings in short texts and examples, addressing the individual thinking and acting of designers [2]. They are the first authors of design methods. One of their decisive aims was to further impart their experience and findings in order to ease and shorten the time necessary to become a fully-fledged designer.
In their further development, design methods and their descriptions changed distinctively. They became more comprehensive and abstract, in order to gain scientific recognition and be suitable for a broad application in different branches. Analyzing this development and the different development stages of design methods makes evident that design methods embody different levels of knowledge concerning the levels of expertise and thus that of abstraction. Investigations of the authors of design methods [5] show that the development of design methods corresponds to aspects of gaining expertise.
This paper addresses the question of what meaning these insights into design methods have in terms of their characteristics, application and impartation. The paper reveals certain characteristics of design methods and their authors concerning expertise, and concludes with important aspects for a more "design methods-suitable" education. The characteristics of experts, expert knowledge and expert learning-styles are key factors in these considerations.

Keywords: design methods, design research, expertise, expert knowledge, education

1 INTRODUCTION
Imparting designing and design methods is an ever-present topic in design research and design education [22]. There are many investigations and approaches towards teaching design methods efficiently [23]. The approaches are very diverse and do not agree with one another. They reach from the training of skills and abilities, the implementing of certain learning-cycles in curricula to collaborative teaching projects. All these approaches are undoubtedly very useful and address important aspects in teaching designing and design methods. However, these single approaches seldom encompass all of the important aspects, and in some points, they oppose one another (e.g. teaching design methods before machine parts and vice versa).
The main gap in all these approaches, from the author's point of view, is that they have neither defined (cognitive) requirements on a successful designer nor defined (cognitive) characteristics of design methods. Therefore, the cognitive prerequisites for the flexible application of design methods and the appropriate teaching methods are still uncertain. In addition, there is no exact definition of design methods in the sense of knowledge and learning material. This paper intends to expose the (cognitive) characteristics of design methods, define requirements, and deduce the corresponding teaching methods. With these insights, some new aspects and strategies in the efficient imparting of design methods will ensue.

2 LEARNING FROM THE DEVELOPMENT OF DESIGN METHODS
The basic idea of this analysis is the consideration of the development of design methods and the authors of these methods. Designers have gained experience and insights into designing in their daily work and have so become competent designers. Some of these competent designers started to

formulate design methods in order to transfer their knowledge and findings to other designers, making it possible for them to develop their competence as designers in less time ([8], see figure 1).
The idea of this paper is to learn from the authors of design methods and their development, as well as and the development of design methods and their characteristics, and then transfer these findings to teaching design methods.

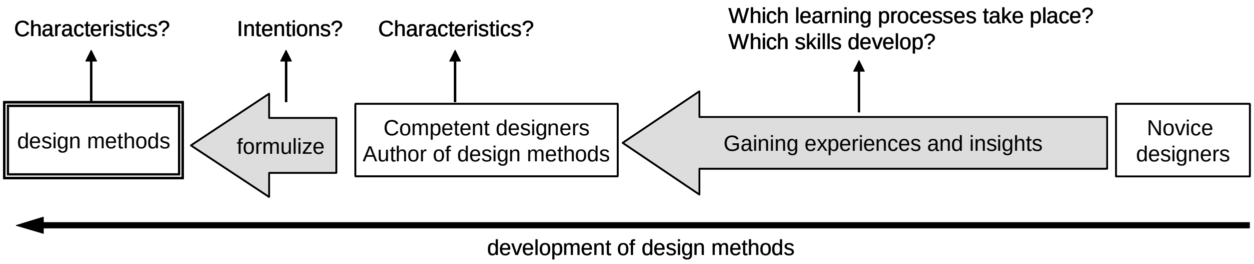

Figure 1. Subject of the analysis

This paper is based on the assumptions that authors of design methods are experts in their domain and that design methods are therefore expert knowledge [8]. In order to prove these assumptions, the characteristics of experts and expert knowledge are described and compared to the characteristics of the authors and design methods themselves. In detail, the characteristics of expert perception, knowledge representation, problem-solving behavior and memory are addressed.

3 AUTHORS OF DESIGN METHODS AS EXPERTS

Authors of design methods have designed and taught over 10 years and so they can be seen as experts in their domains [8]. They dispose over many experience, a broad knowledge-base and distinctive skills and abilities. As experts, they have certain characteristics that are important when they apply design methods. So, these characteristics must be known when teaching design methods, in order to integrate them into the teaching aims. Teaching designing is not only about teaching design methods, it is also about teaching the characteristics of experts. The following sections will describe these general characteristics.

3.1 Characteristics of expert

Experts dispose over certain cognitive capabilities and characteristics that are decisive for their outstanding cognitive performance. These cognitive characteristics (perception, knowledge representation, problem-solving behavior and memory) play a crucial role while designing and when externalizing and formulating knowledge. Therefore, these characteristics are analyzed concerning the design methods and the demands on designers. From these, the characteristics of design methods and cognitive demands on the designer can be inferred. These findings allow one to deduce suitable teaching methods for designing and design methods.

3.1.1 The perception and knowledge representation of experts

The perception of experts differs decisively from that of novices. Experts do not perceive single elements, but rather *meaning based patterns*. Therefore, they also can perceive problems in meaning based patterns. The *meaning based perception* is founded on the extensive knowledge of experts.
Furthermore, experts are able to attribute the external characteristics of a problem to the *fundamental principles*. Chi, Feltovich and Glaser observed test persons which were experts and novices in a certain knowledge domain. They realized that novices clustered the problems according to their *external surface features*. Experts, on the other hand, clustered them by fundamental principles, such as the *conversation of energy* or *Newton's second law* [6, 7]. Anzai observes that experts tend to structure problems of physics using abstract terminology, such as *mass* or *frictionless surface*. Novices, however, use colloquial terms such as *block* or *rope*. The perception and thus the problem description of experts is quite efficient, since they offer better approaches for solutions.
Concerning design methods, these results show that the technical and abstract terminology used in design methods is intended (knowingly or unknowingly) to reduce technical problems to *abstract terms*, *principles* and *functions*. Thus, design methods suggest a perception, representation and structure of problems that correspond to that of experts.

Accordingly, design methods, e.g. function structure or effect structure (Wirkstruktur), can be understood as the *meaning based problem perception* and *representations* of experts [8].

3.1.2 Problem-solving behavior of experts

Experts distinguish themselves by their problem-solving behavior. Besides the *domain-specific patterns* of problems, they also dispose of many domain-specific problem-solving methods and solutions, which are partly linked to the different patterns of problems. Therefore, when experts are confronted with a certain problem, they can attribute it to a certain pattern and find a suitable problem-solving method or solution. Novices do not have this ability.

For example, experts can apply a very efficient and effective *means-end-analysis*. They can structure the problems into suitable sub-problems. They possess an extensive mental store of problem-solving procedures, which they can immediately link to the sub-problem or the complete problem.

Novices, on the other hand, have to generate these problem-solving procedures for each individual case. Experts have the advantages that they making fewer mistakes due to their knowledge of and experience with solution methods. They are already familiar with suitable analyses and the structures of problems. Therefore, they can focus their attention on the essential parts of the problems. This results in the great flexibility of experts in new problem situations [9].

These facts have an important meaning for the classification and understanding of design methods. Design methods describe in many parts the problem-solving behavior that is typical for experts. Many researchers have established that a flexible and suitable procedure leads to good solutions [10, 11]. This point also shows that the demand for flexibility in design corresponds to the demand for expertise.

The question is whether design methods provide this flexibility. The answer is definitely 'no'. The user of the design method has to provide this flexibility. The successful application of design methods requires a flexible application and adaptation that only can be provided by experts. However, design methods support one in becoming an expert by imparting expert problem-solving strategies and problem structuring and representation [8].

3.1.3 Knowledge representation of experts

Knowledge is stored in long-term-memory. The knowledge of experts is much more comprehensive and is represented on more abstract levels than that of novices. Experts can recall the knowledge in a very structured and efficient way. Novices do not possess too much knowledge on an abstract level. Rather, they dispose of specific knowledge on a concrete level. This knowledge is less flexible and applicable than the abstract expert knowledge. Furthermore, the knowledge of experts contains fewer faults than the one of novices.

The abstract representation of knowledge also allows the efficient recalling of knowledge and processing. In addition, the problem-solving procedures of experts are automated and stable. These facts explain why expert problem-solving behavior is exact and quick.

3.1.4 Meta-cognition and strategies of experts

Besides the efficient perception and representation of knowledge and problem-solving behavior, experts have at their command refined and distinct meta-cognitive knowledge, meta-cognitive skills and meta-cognitive strategies. These are especially revealed in planning, observing, control and regulation-processes [12]. The meta-cognitive knowledge of experts represents their own knowledge base, knowledge about their own cognitive abilities, and knowledge about the difficulties of various tasks.

Experts plan their procedure much better than novices do. Moreover, they can adapt their plans to their own cognitive resources and the problem's degree of difficulty. Thus, they can forecast possible problems and figure out strategies to avoid them. They are more sensitive to the requirements of the problems and can recognize relevant information better than novices can. They are able to observe themselves during the problem-solving process and can adapt their thinking and acting according the progress of the process. In addition, they control their own progress and compare it to the plan. With these strategies, they improve their planning skills and avoid discovering mistakes and failures too late. If they perceive divergences from the plan, they are able to adjust their thinking and acting [13].

3.1.5 Implicit knowledge of experts

Experts are not conscious of large parts of their knowledge, but use them anyway. Many automated processes belong to this implicit knowledge, which provides more free cognitive capacity when thinking. [14]

Implicit knowledge plays a decisive role in design. Many authors mention the importance of subconscious knowledge [2, 15].

3.2 Expert learning styles

Experts have certain styles of learning; one could say that they apply expert-learning strategies. These learning styles are tactic-learning and strategic-learning [4].

Experts are people who are aware of their position as learners and they actively reflect and contemplate upon their learning progress [13]. They dispose of knowledge about problems, strategies and themselves as learners. Additionally, experts have a distinctly high level of motivation.

The decisive elements of these learning styles are metacognition, which contains aspects of planning, controlling, evaluating, and regulating. The elements of strategic and tactic learning styles are detecting domain-specific procedures, domain-specific working-steps and recognizing patterns and methods. These styles of learning enable experts to learn very efficiently, flexible and self-organized. These elements of strategic- and tactic-learning provide many effects that are also demanded of designers and that correspond to many elements that are implemented in design methods. So, these learning styles seem to be very interesting when teaching design methods and should perhaps be implemented when teaching them.

3.2.1 Tactic-learning

Tactic-learning is to memorize sequences of operations (actions) to solve a certain sub-problem. When dealing repeatedly with similar sub-problems, experts first learn the steps of action necessary to solve the problem [24]. Therefore, tactic-learning describes the process by which certain actions and rules for solving certain sub-problems are acquired. The term tactic refers to the problem-solving methods, which enable one to reach a specific goal.

In complex domains, such as designing, the same problem seldom appears more than once. However, components of the problem may reappear and the learners can memorize those, which are linked to a suitable problem-solving method in the sense of a sequence of action-steps. So, this type of learning seems to be effective to learn designing and design methods.

For example, the design methods function structure suggests setting up sub-problems in order to provide the possibility to use tactics. Furthermore, the suggestions of working methods in design methods such as setting up lists, comparing lists or document facts initiate tactics. Design catalogues [Roth, Koller] provide solutions for sub-problems and so provide tactics in the sense of domain-specific-knowledge.

Tactics in design are little working steps and solutions for sub-problems. So, tactics are essentially action based operations and working methods. Disposing of tactics leads to fewer failures and furthermore to more efficiency during single working steps. Tactics in design are, for example, knowing how to calculate the live time of roller bearings or how to set up a project plan operatively.

3.2.2 Strategic-learning

Strategic-learning refers to how learners organize the solution of the whole problem. Strategic-learning is explained in a test done by Larkin [24]. He compared the problem-solving of experts and novices in the domain of physics. The task they had to solve was as follows:

A block slide along an inclined plane with the length l. The angle of the plane is Θ. The coefficient of friction is μ. The speed of the block on the end of the plane should be determined.

The result of this experiment was that novices chose the method of backward reasoning. They started with the unknown speed v. To calculate v they needed the acceleration and so they searched for an equation that contains a. They worked their way along to a system of equations, which solve the task [25].

Experts used similar equations, but in the inverse sequence. They started with the variable that they could calculate directly, for example with gravitation, and worked forward to the unknown speed. So, they used forward reasoning to solve the problem. Using this strategy, they had to memorize the different sub-goals and know what possibilities of reasoning were relevant to the problem.

When gaining experience, experts learn different possibilities of reasoning with different patterns of the problem. However, learning these kinds of reasoning and strategies differs from domain to domain. Experts adapt their strategies and their working styles to the specific requirements of the various domains.
While developing software, a crucial difference between experts and novices could be observed [26]. Experts decline to solve problems first with a broad search, but novices apply an in-depth search in the beginning.
Therefore, the development of expertise in a certain domain entails figuring out which strategy is most relevant and suitable for the domain. A physicist learns to solve a problem with forward reasoning while software programmers learn to first apply a broad search. Strategic-learning means adapting one's approach to the structural composition of problems in a specific domain.
Strategic learning is extremely important when learning designing, but it is also very difficult because the field of designing is so broad and the problems are so different. Strategic-learning in the field of designing means to learn many different strategies and how they are applied and adjusted.
For designing, a broad search would be comparable to the creation of solution variants. Therefore, the design methods can be understood in this context as suitable strategies of experts in the domain of design. Furthermore, the function structure can be seen as an appropriate method to structure problems, and the morphological box as a method to structure sub-solutions. But a broad search is not the only strategy in design. When considering evaluation methods, it becomes evident that they initiate in-depth searches when narrowing down the scope of solutions.
So, it becomes clear that designing requires different strategies and tactics according to the complexity and variety of the task. This is one decisive reason why designing and design education is so difficult and extensive. Furthermore, it explains why teaching methods from other disciplines are not directly transferable to design education. Thus, the question of what is the best strategy for designing is not simple to answer. The multivarious aspects of designing inevitably require many different strategies depending on the disciplines involved, the situation, the stages of the design process, etc. (see chapter 5)

4. DESIGN METHODS AS EXPERT KNOWLEDGE AND STRATEGIES

Analyzing design methods from an expert's point of view shows that they support problem-solving and impart the knowledge and strategies of experts. This becomes visible, if you compare the characteristics of experts with design methods. They show how experts perceive, represent, structure and approach a design task.

4.1 The VDI guideline 2221 as metacognitive knowledge and strategy

Considering, for example, the VDI guideline 2221 or 2222 one can identify the following characteristics that initiate thinking and acting of experts (see Figure 4).
The working steps *clarify the task* and *define a requirement list* lead to a comprehensive task analysis and task representation that are typical for experts. The working steps *determine functions and their structure* address pattern matching and meaning-based perception. By setting up a *function structure* the abstract representation of the problem should be enhanced. Furthermore, with the abstract problem representation, a wider scope of solutions can be found. This also supports better access to existing solutions or problem-solving procedures. The working step *search for solution principles and their* combinations tries to start a breadth-first search and generate variants. These are established successful strategies in the conceptual design phases.
The advice *iterate towards and backwards between previous and following stages and fulfill and adapt requirements* can initiate metacognitive processes. By dividing the design process into phases and single working steps, the VDI 2221 provides an efficient and suitable means-end-analysis for the design process.

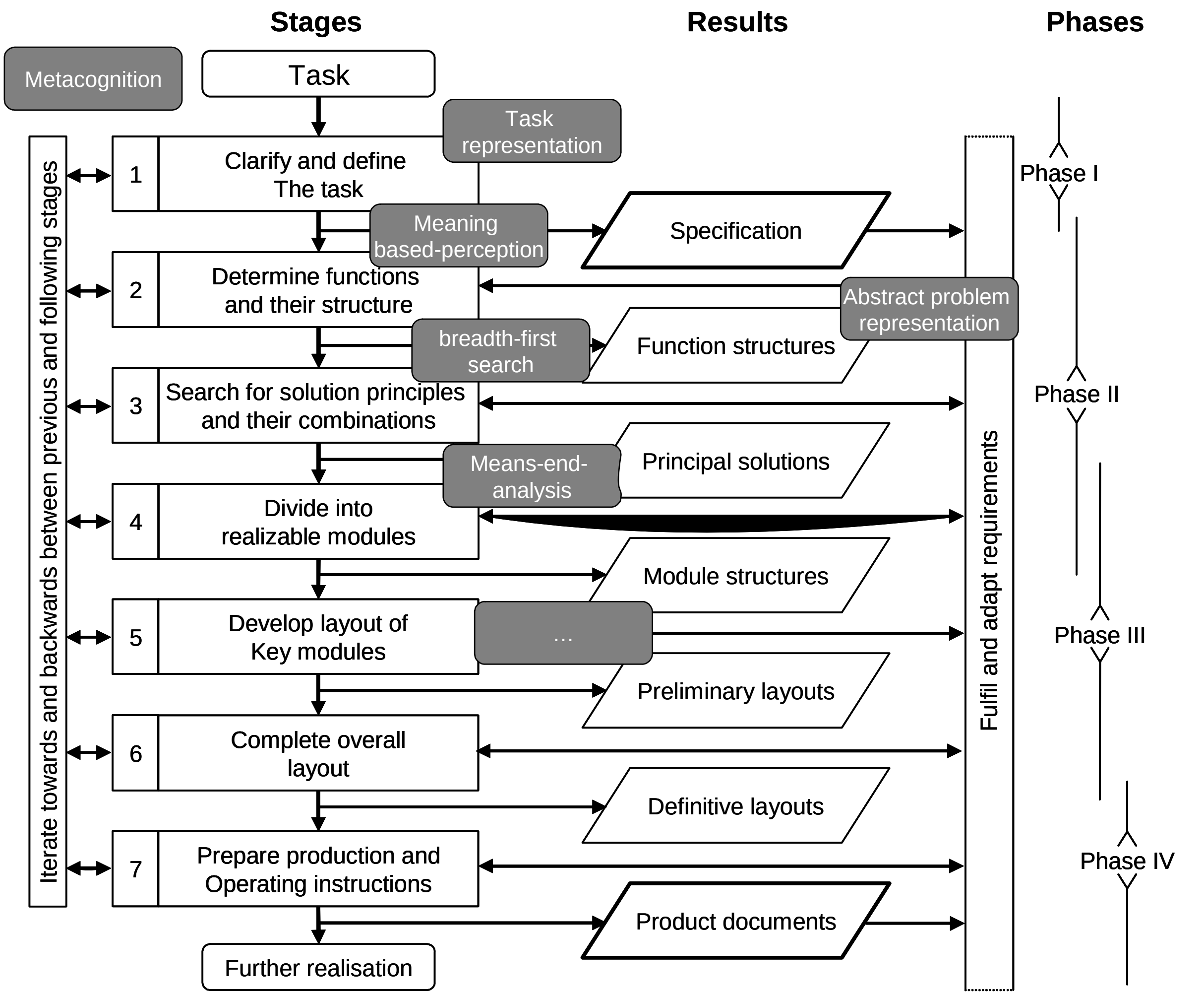

Figure 5. VDI 2221 as expert strategy and knowledge [16]

All in all, the VDI 2221 presents comprehensive knowledge and findings concerning the design process. Therefore, it serves as an abstract reference model of the design process. The VDI guideline 2221 can above all be seen as metacognitive knowledge. Their content and structure basically implement planning, controlling and regulation processes in the design processes and impart meta-cognitive knowledge.

4.2 Function structure as efficient and domain-specific means-end-analysis

Setting up function structures lead to a problem-solving behavior that corresponds to that of experts. Firstly, the function analysis of a technical system initiates pattern-matching processes and abstraction processes concerning technical connection. The function structure themself can be seen as an abstract representation of a technical problem. The terms of the different functions are the abstract terms and principles that provide a better and broader range of solution possibilities. Dividing the overall function into the sub-functions corresponds to the single steps of a means-end-analysis. Identifying the solution determining sub-functions helps to detect the essential parts of the design problems.

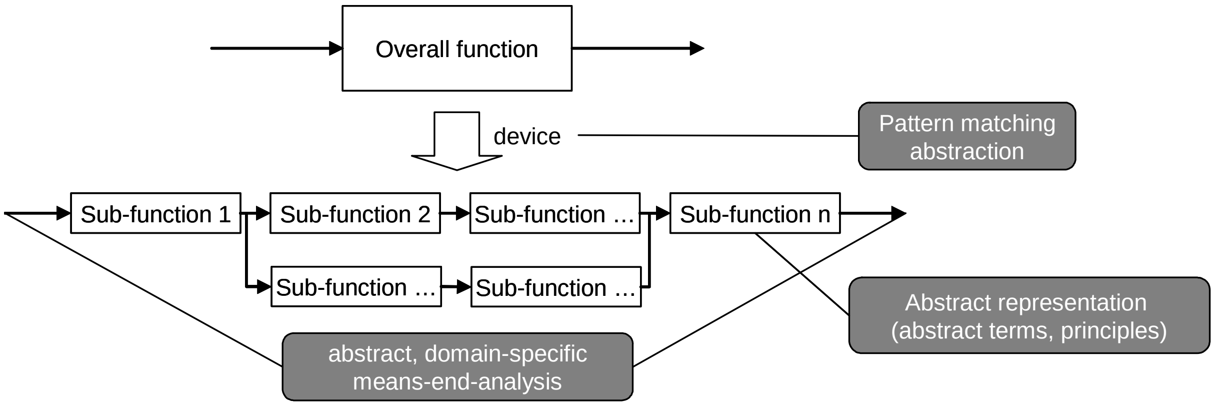

Figure 5: Function structure as domain-specific means-end-analysis

The abstraction initiated by the function analysis can be understood as a domain-specific means-end-analysis. It also provides a reduction of complexity in order to make it suitable for the cognitive capacity [8].
So far, the characteristics of design methods as expert knowledge and strategies have been established as well as the fact that the application of design methods can initiate and support the (problem-solving) behavior of experts. Consequently, they can be understood as externalized expert knowledge. Considering the authors of design methods in their careers and experiences, they are undoubtedly experts in engineering design and in design methods. Due to many years of experience in their professions and activities, they have gained expertise [8, 5]. They have externalized their findings and insights in design methods in order to allow other designers to profit from them (see figure 6).
Regarding this characteristics of design methods the first important aspect that needs to be considered is that design methods are abstract and partly domain-specific in their nature. The second important aspect is that the flexible application of design methods is analogous to expertise in design methods. This indicates that the aim of successful teaching methods should be imparting expertise. Thus, the findings of gaining expertise and the nature of expertise need to be taken into account when teaching designing and design methods.

5 THE REQUIREMENTS LEARNING AND APPLYING EXPERT KNOWLEDGE

This chapter aims to describe the efficient teaching methods to impart expertise. It also explains the necessary learning mechanisms that have to take place to gain expertise.
Learning and teaching theories try to provide mechanisms and hints to minimize the time to become an expert. Therefore, design methods as expert knowledge, and learning and teaching theories as amplifier to gain expertise can be efficient combinations to teach expert knowledge with expert (learning) strategies.

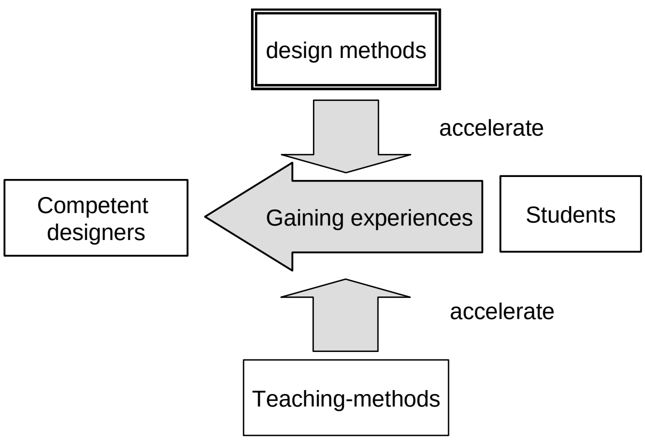

Figure 6. Intention of design methods and teaching-methods

5.1 Elements of expert-learning

In order to be able to apply tactic and strategic-learning certain elements of learning are required. Figure 3 shows the crucial elements of expert-learning. The central point of expert-learning is meta-cognition. Metacognition is the basis for strategic-learning, self-assessment and control over the learning process. Here, it is important to answer the question of how to acquire metacognition. Furthermore, the level of motivation, when learning, is an important factor of success. Furthermore, the learning types procedural learning, metacognitive learning, acquaintance of metacognition, and problem-solving operators are essentially. The 3 stages of learning according to Anderson lie behind these types.

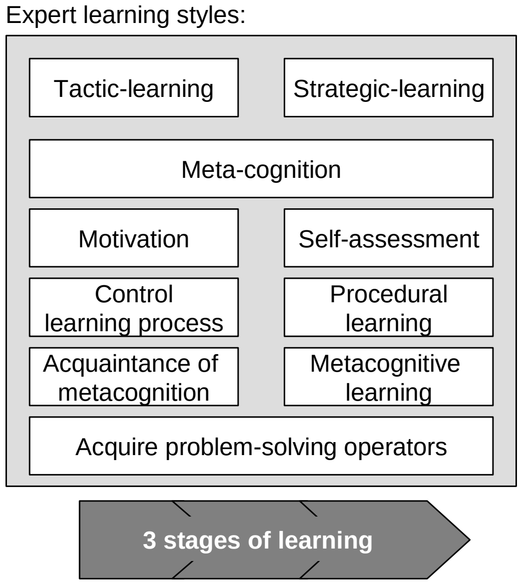

Figure 3. Elements of expert-learning

5.1.1 Three stages of learning

The fundamental learning process indispensable when gaining expertise is the three stages process according to Anderson. There are three stages of learning problem-solving procedures with regard to expertise (see figure 6). This theory states that there are three phases during the learning process: the cognitive phase, the associative phase and the automated phase.

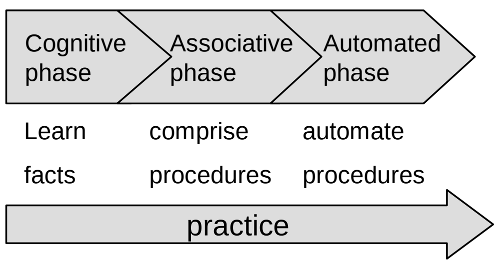

Figure 7. Three stages of learning

1. Cognitive phase: During this phase, facts are remembered that have a meaning for a certain skill or problem-solving procedure. That means a mental representation of what have to be done to solve the problem is generated.
2. Associative phase: During this phase misunderstandings and failures of the problem are eliminated. Additionally, single steps that are necessary to solve the problems become connected. On the end of this phase a successful problem-solving procedure (connection of operators) emerges.
3. Automated phase: This phase is responsible for automating and accelerating the problem-solving procedures. Routines are generated. This increases the efficiency and precision of the problem-solving procedure. Also possible failures in the procedures are eliminated. This is also called tuning.

In order to shorten this time span different learning mechanisms are possible. These are mainly: acquire problem-solving operators and metacognition, procedural learning and metacognitive learning.

5.1.2 Acquire problem-solving operators

Efficient problem-solving behavior depends strongly on the domain-specific and automated problem-solving procedures at one's disposal. According to Anderson [24], there are three ways to acquire these: exploration, analogical reasoning and examples with instruction. Exploring is the most time-consuming way and is not considered here.
Analogical reasoning conceals the problem to find the appropriate operands. Many times operands are overseen or wrongly interpreted. Experiments of Reed [17] show that operands can be efficiently learned with suitable examples with instructions.

5.1.3 Procedural learning

The main goal when gaining expertise is to automate the problem-solving procedures. Automated processes help to let these processes run without using too much cognitive capacity. This also supports meaning based perception and conserves cognitive resources. The automation can basically be reached by practicing and repeating.

5.1.4 Metacognitive learning

Metacognition is a central point of expertise and also of gaining expertise [18]. Learning efficiently requires insights into one's own learning and thinking processes and how to control and regulate them. Successful learners dispose of meta-knowledge concerning learning. With this knowledge they are able to influence their cognitive performance when learning. This metaknowledge can encompass the components represented in figure 8. The metacognitive processes planning, regulating, and controlling are prerequisites for that type of learning.

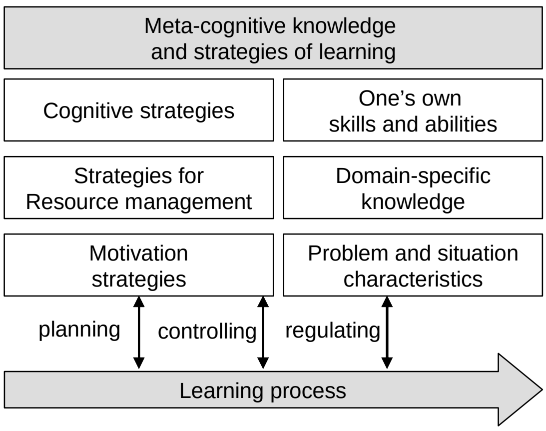

Figure 8. Prerequisites for metacognitive learning

To the cognitive strategies belong the application of repetitions, the strategy of elaboration with finding connections to existing knowledge, examples, analogies, and the strategy of organization in the learning process. The strategy of organization encompasses structuring and connecting the learning material. Concrete working steps of this strategy are to categorize knowledge, create cognitive maps (mind-maps or concept maps) or use the (S)PQ4R-Technique according to Thomas and Robinson ((Survey) Preview – Questions – Read – Reflect – Recite – Review).
The strategy of resource management refers to the learning context. The learning should be able to provide a suitable surrounding by oneself including an appropriate time planning.
Motivational strategies enable a person to guard themselves against competitive influences. These strategies also support to save cognitive resources.

5.1.5 Acquaintance of metacognition

Metacognition and metacognitive knowledge as central elements of expertise and gaining expertise is teachable according to Sternberg. With certain teaching methods metacognition can be activated and increased. These teaching methods are instruction (meaning of meta-cognition, information about metacognition, etc.), regulation checklists (see figure 9), SOAR (Feedback), self-asking techniques, thinking aloud, failure critics with feedback, and visualization techniques, such as mind-mapping or concept-mapping [19].

A Regulatory Checklist

Planning
1. What is the nature of the task?
2. What is my goal?
3. What kind of information and strategies do I need?
4. How much time and resources will I need?

Monitoring
1. Do I Have a clear understanding of what I am doing?
2. Does the task make sense?
3. Am I reaching my goals?
4. Do I need to make changes?

Evaluation
1. Have I reached my goal?
2. What worked?
3. What didn't work?
4. Would I do things differently next time?

Figure 9. Regulation checklist according to King [20]

Working with the regulation checklist shows that students can provide a better planned and a more systematic problem-solving behavior. Failure analysis with feedbacks especially trains the aspects of controlling and evaluating. The feedback helps the students to recognize failures and their sources and learn how to avoid them. Also failures in their understanding and knowledge can be corrected with a feedback. Thinking aloud is an effect method to develop metacognitive knowledge and skills. The method helps to increase attention, think more systematically and increase the knowledge about oneself. Further it supports to recognize failures in early phases. This method can be made more intensive by speaking to a second person, who gives feedback. This method is also known as SOAR (Program Stress on analytical Reasoning) [21].

5.2 Initiating experts knowledge and strategies

This chapter visualize the findings how to tech expertise and adapt them the design education. Figure 10 shows on the left hand the revealed cognitive requirements for teaching design methods and designing. They are composed of the characteristics of experts and of the broad field of designing. The suitable teaching-methods that help to meet these requirements are listed on the right site.
The central teaching elements that support gaining expertise are instruction, examples, practicing, repetitions, correction, regulation checklists, metacognitive learning, failure feedback, thinking aloud and visualization techniques. These should be implemented in teaching designing and design methods. Applying these in teaching design includes the aspects shown in the teaching concept of figure 10. This concept can be understood as a checklist of available efficient teaching methods.

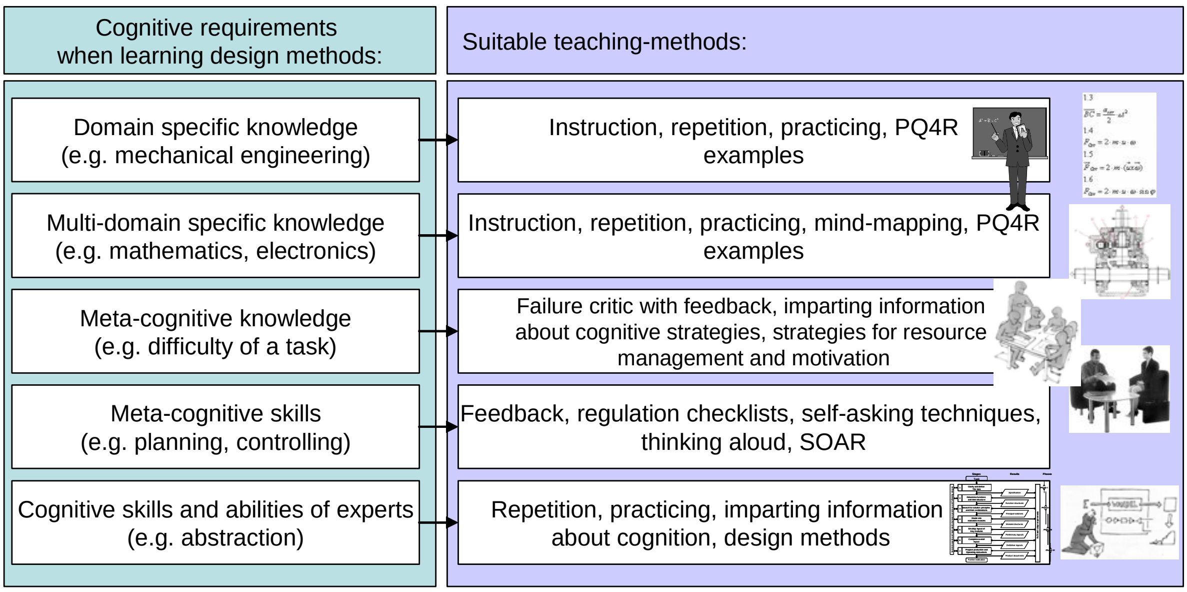

Figure 10: Teaching methods for initiating expertise in design

6 CONCLUSION

The paper reveals reasons why it is so difficult and time-consuming to learn and teach designing and design methods – the demand of expertise and the fact that design methods are expert knowledge and strategies and the point that designing encompass so many knowledge domains.

It becomes visible what (cognitive) steps design methods support (e.g. the VDI 2221 supports an abstract means-end-analysis). Applying design methods and being an expert seems to be very close.

The fact that design methods require expertise leads to findings about gaining expertise. This research field provides many insights that are helpful to know when teaching such a difficult field. Some of the presented teaching-methods are known but not contemplately used when teaching design methods.

An interesting aspect is that design methods are similar to the mentioned teaching-methods and meta-cognition. They also contain checklist and advice to plan, control and regulate.

This paper gives a better understanding of the characteristics and the cognitive requirements of design methods and so provides new hints how to teach them appropriately to their characteristics and cognitive requirements. The teaching-methods, which are especially developed for gaining expertise are presented and connected to the cognitive requirements. Another important message of this analysis is to adapt the expectations of the efficacious of a teaching-concept to the fact that we want to impart expertise. Reaching this goal is quite challenging and need to be adjusted to the possibilities we have in the framework of teaching.

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