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EVALUATION OF A METHODOLOGICAL TRAINING IN DESIGN EDUCATION

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ABSTRACT
Design education has to achieve high quality, in order to prepare engineering design students to cope with the complex demands of their future working life. Therefore, it has to be empirically proved in how far an educational concept contributes to that goal. In this paper a concept of a methodological training course and an empirical study conducted in order to evaluate the training course are introduced. The aim of the study has been to find out if the students applied the methods taught in the course in an appropriate way. For this purpose a qualitative, process-oriented research approach was implemented, which analysed the participants' cognitive operations during method application and compared them to the method's intentions and requirements. The results indicate that students applied most methods correctly but had difficulties to grasp the whole range of the more complex and demanding methods "QFD" (Quality Function Deployment) and "TRIZ" (Theory of Inventive Problem Solving). Reasons for these difficulties are discussed and measures are proposed that aim at the adaptation of the complexity of these methods to the designers' experience. Finally, conclusions for design education in general and the research on educational concepts in design are drawn.

Keywords: design education, methodological training, evaluation of educational concepts, problem-solving theory

1 INTRODUCTION
At the present time substantial large-scale changes in industry take place. People's everyday life becomes more complex and so do the technical products and their development processes. In order to meet the increasingly complex demands of modern working life, supporting designers in their daily work and preparing the students of engineering design to cope with these requirements gain more importance than ever [1].
But how should an effective design education look like? Over the past years, plenty of attention has been paid to didactical aspects of design education. Experts agree that a systematic education, which imparts methodological approaches, can enable novices to deal with complex design tasks [2], [3], [4]. Additionally, results of previous research emphasise the relevance of process knowledge for the improvement of creativity and design performance [5], [6]. Moreover, most authors support educational concepts that apply project-based learning in a team setting [7], [8].

But it is not enough simply implementing training courses in design education, which allow groups of students to practice methods on a design case. Due to Badke-Schaub's [1] postulation for a human-centred design methodology that enables designers to overcome the barriers of their limited capacity of conscious thinking, it has to be proved if educational concepts in design contribute to this goal. Lately, there have been many approaches to evaluate teaching concepts in design using different methods to "measure" success: Some researchers simply reported their experiences [e.g. 9], others had a look at the changes of students' grades and their design performance [10] or employed questionnaires to gain insights into the students' perspective [10], [11].
In this paper, a concept of a methodological training in design education, which is offered at the Institute of Product Development at the Technical University (TU) of Munich, will be introduced

(section 2). Then, an empirical study resulting from a cooperative project between the TU Munich and the Institute of Theoretical Psychology Bamberg is described, which suggests a new approach for the evaluation of teaching concepts (section 4) against the background of cognitive psychology (section 3). Results of the study (section 5) provide implications for systematic design education (sections 6 and 7).

2 FOCUS AND ORGANISATION OF THE METHODOLOGICAL TRAINING

Each semester, the Institute of Product Development offers an elective course on systematic approaches for master students from mechanical and electrical engineering in order to teach them methodological proceeding in design. During their studies students learn a lot of technical know-how, there are even lectures on design methods. But within the students' regular curriculum there is little possibility to practice technical and methodological knowledge. Due to this fact, practical trainings are compulsory for engineering students. This methodological training is one possible choice. In addition, various other trainings concentrating on specific technical topics, e.g. production, automotive engineering or astronautics, are offered to the students.
The general didactic focus of this course is to deepen the students' understanding of the design process and of engineering design methods, emphasising the following aims:

- support students in getting acquainted with the different, commonly known design methods,
- encourage students to apply these methods to a concrete design case,
- help students to gather experience with the application of methods,
- facilitate the experience of team work in the design process.

Moreover, students act as facilitators in this training course, i.e. doing a short presentation, guiding, leading discussions and keeping the team on track.

Thus, students mainly work on design methods in this training – it is not about the product itself. The concrete design case may vary over the courses. The main focus lies on the learning process how to apply design methods. In the course the study was undertaken, the task was to develop a table vacuum cleaner. Currently, students are working on designing a juice squeezer.

As the practical training is limited in time, only a selection of methods can be applied and discussed. The training concept includes the following methods: Weak-Point Analysis, Brainstorming, Requirements List, Quality Function Deployment (QFD), Functional Modelling, TRIZ, Synectics, Morphologic Chart, Weighting and Rating, Design for X and FMEA (see also Table 1). These methods are suitable for different phases of the design process, e.g. described by the Munich Procedural Model [12], [4] (Figure 1).

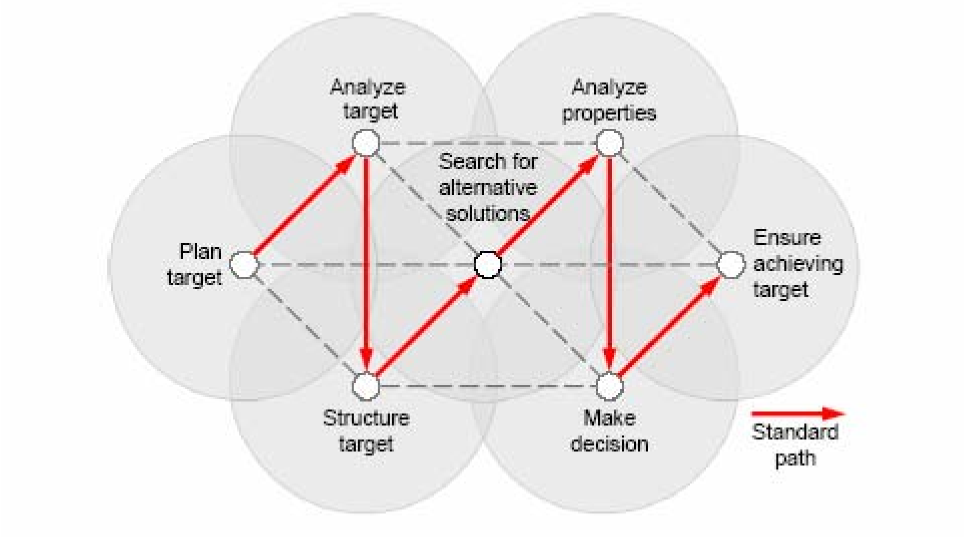

Figure 1. The Munich Procedural Model [12], [4]

In the course, the methods “Weak-Point Analysis”, “Brainstorming”, and “Requirements List” support the early phases of planning and analysing the target. “QFD” and “Functional Modelling” are employed in order to structure the target, while “TRIZ” relates to both “target structuring” and “searching for solutions”. An alternative method that facilitates the solution finding process is “Synectics”. The process steps “analysing properties” and “decision making” are aided by the methods “Design for X”, “Morphologic Chart”, and “Weighting and Rating”. Finally, the method “FMEA” helps to ensure target achievement.

The course is coordinated and supervised by a team of two to three Ph.D. students. It is designed for ten participants and takes place ten times during the semester. Each session lasts six to seven hours. During nine sessions different methods are taught and applied on designing a table vacuum cleaner. In the last session a final presentation resuming the whole design process takes place. Table 1 depicts the sequence of the applied methods.

Table 1. Sequence of the methods taught and practiced in the training course

Session 1	Weak-Point Analysis
Session 2	Brainstorming, Requirements List
Session 3	Quality Function Deployment (QFD)
Session 4	Functional Modelling
Session 5	TRIZ
Session 6	Synectics
Session 7	Morphologic Chart, Weighting and Rating
Session 8	Design for X
Session 9	FMEA
Session 10	Final presentation

For this course preparation is expected: Students are advised to look into the method to be applied before each session. For further preparation they get handouts with information on engineering design methods based on Lindemann [4]. These handouts describe the aims and steps to be taken for the different methods. This procedure should assure that the participants have a basic understanding of the specific design method.
In order to get acquainted with method application, the participants have to act as moderators two times during the duration of the training course. After each session insights gained by the participants are discussed and reflected. The supervisors give supplementary input of advantages and disadvantages of a method.

3 BACKGROUND AND OBJECTIVES

3.1 Theoretical background

Designing a technical product is a process of thinking and problem solving [13], [14]. Moreover, many authors define the work of engineering designers as complex problem solving [15], [16], [17], [18], [19]. In the field of product development, complex tasks are prevailing that are characterised by multiple factors of influence, high interconnectivity of the relevant variables, high levels of intransparency, time pressure and conflicting goals [2]. Dörner [20] considered these factors as characteristics of complex problems and proposed a model of action regulation, which describes steps to be taken in order to succeed in dealing with complex environments (see Figure 2).

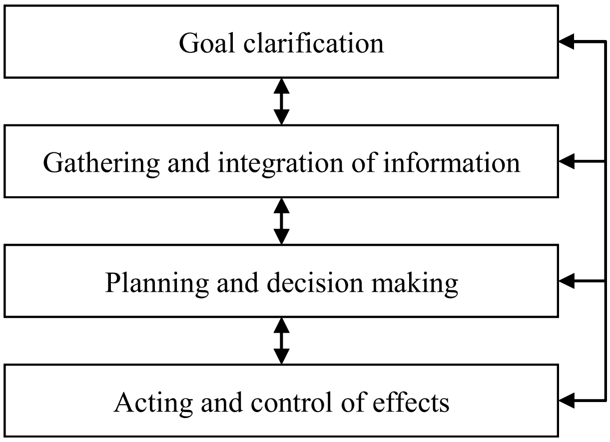

Figure 2. Stages of Action Regulation according to Dörner [20]

Complex tasks, such as design tasks, require concretising and specifying the goal that is often too global and ill-defined. In addition, persons who solve complex problems have to gather information about the segment of reality they are acting in, e.g. which variables the field is composed of and how the actual situation will develop in the future. Various data have to be integrated into a model by linking interrelations between variables. Before acting, it is crucial to plan the further proceeding by constructing possible paths of action (which will be called "solution finding" in the following) and anticipate their probability of success. After that, decision making and acting must follow. Finally, it has to be checked whether the chosen action has led to success.

As the arrows in Figure 2 underscore, the various stages of action regulation do not need to occur in the depicted sequence. Iterations and jumping back to previous stages are possible and even necessary in complex problem solving. Obviously, there is a high degree of similarity between the stages of action regulation and the recommended proceeding proposed by design methodology in the context of engineering design [3], [4], [12] (see also Figure 1).

Badke-Schaub [21] expanded the validity of Dörner's model from individual problem solving to group context and added one further dimension. She emphasised the importance of both, task related problem solving activities (as they are displayed in Figure 2) and activities that refer to the organisation of the group, such as coordination, information management, and structuring the group. This approach seems to be very expedient for the design context, as modern work organisation in the field of product development often centres on multidisciplinary design teams.

Problem solving theory provides the background for the study introduced in this paper, which means that hypotheses (see section 4.1) as well as research methods (see section 4.2) refer to the theoretical conclusions reported in this section.

3.2 Objectives

The aim of the study has been to evaluate the concept of the methodological training offered to graduate students at the TU Munich. We have intended to find out whether methods taught in the training course were applied appropriately by the participants – that means according to the methods' goals. Therefore, we analysed the participants' cognitive operations during method application and compared them to the method's intentions and requirements. We have aimed at observing the methods that are not applied correctly by the students and discuss the reasons, taking into account the restrictions of the specific method and the constraints of the current situation. In particular, we have set out to modify the teaching concept of the observed course, if necessary, and to draw implications for systematic design education in general.

4 HYPOTHESES AND METHODS

4.1 Hypotheses

The intention of the study has been to find out, whether methods taught in the training course were applied by the participants according to the intended rules. Thus, we had a thorough look at the intentions and goals of the particular methods described in literature [3], [4]. Then, we deduced from problem solving theory which cognitive processes are needed to meet the methods' goals. Hypotheses were formulated separately for each method, which point out the cognitive processes that should take place during application of the specific method compared to other methods of the training course. Table 2 depicts the methods applied in the course, their goals, and the cognitive processes needed to achieve the method's goals.

Table 2. Methods' goals and necessary cognitive processes

Method	Goals	Cognitive processes needed to meet the method's goals
Requirements List	Documentation of requirements	Goal clarification
Quality Function Deployment (QFD)	Transform customers' wishes into technical criteria; detect interrelations between criteria; deduce focal points	Integration of information, Priorisation
TRIZ	Clarification of the problem; early solution finding	Integration of information, Solution finding
Brainstorming and Synectics	Creative production of solution ideas	Solution finding, no Evaluation
Morphologic Chart	Documentation of partial solutions; reduction of the variety of partial solutions	Evaluation
Weighting and Rating	Provide an objective decision base	Evaluation
FMEA	Systematic analysis of malfunction sources	Control of effects

Obviously, the creation of a "Requirements List" requires cognitive operations that clarify the desired goal.

The method "QFD" aims at the transformation of customers' wishes into technical criteria and helps to detect interlinkages between variables with the aid of the "House of Quality". Thus, there are integrative processes to be done during the application of this method, such as pointing out relations between variables. The outcome of this process should be the deduction of focal points of the

development work. Therefore, during the application of "QFD" additional cognitive operations are needed that expose hierarchical relations within a set of variables, such as priorisation.
The aim of "TRIZ" is to detect undesired side-effects of desired functions and to support the early solution finding processes in order to avoid these side-effects. Complex information management processes, such as the integration of information as well as processes of solution finding are crucial to meet the method's goals.
"Brainstorming" and "Synectics" target at the facilitation of creative solution finding processes, in which the quality of solutions is of secondary importance. Therefore, processes of solution finding without evaluation of the solutions were expected.
The generation of the "Morphologic Chart" serves as a method to document existing partial solutions and to combine a general solution concept. In the observed course, the "Morphologic Chart" was also used to reduce the variety of partial solutions. That is why we expected an increase of evaluation processes during the application of this method.
Obviously, weighting methods require evaluative processes.
Finally, the method "FMEA", which aims at the detection of malfunction sources, requires at first hand cognitive operations that control facts and effects.

The methods "Functional Modelling" and "Design for X", which are both taught in the training course, were excluded from the analysis, as they were applied under division of labour and not by all participants of the training course.

4.2 Research Methods

As some authors highlight, it is necessary to analyse the whole design process (instead of focussing only on the results of the process) in order to understand what is going on in designers' minds [e.g. 22], [14]. Therefore, we focussed in our study on the development of students' cognitive processes over time during the methodological training. But as researchers do not have direct access to designers' thinking processes, these have to be approached in an indirect way. Thus, we analysed the participants' verbal interaction, assuming that communication in team provides an access to their thinking processes.
All ten sessions of the training course were observed by a trained psychologist (first author) and video-taped. The observed interactions were analysed by categorisation of each single communicative act that occurred during the design process. For this purpose a slightly modified version of the categorisation system KATKOMP [23] (see Table 3) was employed, which had been developed for the purpose of analysing complex problem solving in design teams.

Table 3. Structure of the categorisation system KATKOMP

Focus	Category
Content	Goal clarification
	Solution finding
	Information management
	Evaluation
	Decision
	Control
Process	Planning
	Information management
	Evaluation
	Decision
	Control
Interpersonal Relations	Expression of emotions

KATKOMP is based on the assumption that designers working together in a team have to deal with the design task itself, but also have to engage in organising the group process (see also section 3.1). Thus, KATKOMP distinguishes three main foci of action, named “Content”, “Process” and “Interpersonal Relations”. Both “Content” and “Process” include a set of main categories, which are related to the demands of problem solving [20] and design methods [3], [4]. These categories are subdivided on a third level into observational codes.

As pointed out in section 4.1, we assumed that under correct method application these codes, which characterise cognitive operations representing the method’s goals, would occur more often during the employment of one particular method than during the application of other methods. Therefore, the statistical analysis focused on the distribution of specific observational codes representing a method’s goal comparing the phases during the application of that particular method and the employment of all other methods in the training course, which was calculated by χ^2-tests.

The χ^2-test according to Pearson tests the null hypothesis, if the cognitive processes that are needed to achieve a method’s goal are equally distributed during the application of the specific method and the employment of all other methods in the course. A correct method application is supposed to be indicated by an increase of those cognitive operations that represent the method’s goals during the employment of this method compared to all other methods. This instance will be shown by the descriptive differences in percentages of observational codes during the particular method versus all other methods as well as by a statistically significant result of the χ^2-test.

The important values of the χ^2-test are the following:
The characteristic χ^2 provides a description of the present data in reference to the research question (equipartition of observational codes during the application of the particular method compared to all other methods). The degrees of freedom (df) describe the limit of tolerance in which the statistical value χ^2 can range. As the crosstabulation of the χ^2-tests consists of four cells, and the number of approximated parameters amounts three, the degrees of freedom for the χ^2-tests used here account for 1 (4 minus 3). The significance value “p” indicates the probability to obtain this or an even more extreme value of χ^2 under validity of the null hypothesis. Therefore, if the value of “p” is very low, one would reject the null hypothesis and assume a significant difference in percentages of observational codes under the two constraints (application of the particular method versus all other methods of the course).

5 RESULTS

Table 4 depicts the methods applied in the training course, the cognitive processes that are expected to increase or decrease with the appropriate method application, the percentage of these specific cognitive processes (relative to all cognitive processes that took place) during the application of the particular method and during the application of all other methods (mean), and the statistical values of χ^2-tests.

Results indicate that most of the methods taught in the training course were applied appropriately by the participants, which means that the students succeeded in attaining the methods’ goals. This could be observed for the following methods:
As presumed, during the creation of the “Requirements List” participants showed a statistically significant increase of cognitive operations that clarify the goal state (3.4 percent during the application of this method versus 0.8 percent during the employment of all other methods). While applying the creativity aiding methods “Brainstorming” and “Synectics”, the number of solution finding processes increased (from 16.3 percent to 38.8 percent), whereas the number of evaluative processes decreased (from 27.6 to 15.2 percent), this is consistent with the methods’ intentions. The method “Morphologic Chart” as well as “Weighting and Rating” methods succeeded in supporting participants’ evaluative processes (41.1 percent versus 24.6 percent for “Morphologic Chart”, and 32.0 percent versus 25.6 percent for “Weighting and Rating”). Moreover, during the application of the method “FMEA” control processes in order to detect sources of error increased (from 0.2 to 0.7 percent).

Table 4. Results of the χ^2-tests

Method	**Cognitive Process**	**Percentage M[1]**	**Percentage O[2]**	**χ^2**	**df**	**p**	**C[3]**
Requirements List	Goal clarification	3.4	0.8	69.5	1	<0.01**	yes
QFD	Integration of information	26.6	10.2	374.8	1	<0.01**	yes
	Priorisation	0.5	1.4	13.4	1	<0.01**	no
TRIZ	Integration of information	8.4	15.4	21.9	1	<0.01**	no
	Solution finding	23.2	18.0	8.4	1	<0.01**	yes
Brain-storming and Synectics	Solution finding	38.8	16.3	266.6	1	<0.01**	yes
	Evaluation	15.2	27.6	63.4	1	<0.01**	yes
Morphologic Chart	Evaluation	41.1	24.6	114.9	1	<0.01**	yes
Weighting and Rating	Evaluation	32.0	25.6	17.8	1	<0.01**	yes
FMEA	Control of effects	0.7	0.2	5.9	1	0.02*	yes

[1] Percentage during application of that particular method
[2] Percentage during application of other methods
[3] Hypothesis confirmed?
* Result significant at the 5% level
**Result significant at the 1% level

Exceptions to these results have been found with the more complex methods “QFD” and “TRIZ”: Obviously, the method “QFD” supported processes of complex information management in the team, which is apparent in the increase of integrative information processing during the application of this method (26.6 percent) compared to other methods (10.2 percent). But “QFD” failed in guiding the students to deduce focal points of the development work. This is shown by the statistically significant decrease of prioritising utterances during the application of this method (0.5 percent) compared to other methods (1.4 percent). That means, the students succeeded in detecting interlinkages between technical variables deduced from customers’ wishes, but they did not manage to set foci for their future work.

The method “TRIZ” facilitated solution finding processes in the team, which amount 23.2 percent during the application of this method and only 18.0 percent during the application of other methods. But “TRIZ” did not contribute to a further clarification of the problem, as it is shown by the decrease of processes of complex information management during the application of this method (8.4 percent) compared to other methods (15.4 percent). Apparently, the participants did not engage in detecting interlinkages between variables, which means identifying undesired side-effects of intended functions in this case. Consequently, in the observed training course the students tried to find solutions building on an ill-defined problem.

6 DISCUSSION

First of all, due to the fact that we counted a great number of observational data during the whole design process, some restricting annotations about the explanatory power of statistical values have to be made:

A larger number of observed cases tend to produce a greater power of a hypothesis test. The power of a test means the probability for the significance of effects (differences between values of the compared samples) existing in the researched population [24]. Calculating statistical tests based on a large number of cases can implicate the fact that the test easily detects effects that do not exist in reality. Therefore, the multiple statistically significant results of χ^2-tests reported in section 5 have to be interpreted with caution. Rather than only noticing the results of the statistical tests, one should also have a look at the descriptive changes of codes under the two conditions that were distinguished in this study, as they provide hints about the relevance of the statistical results.

The main question to be discussed at this point is why the students had problems especially with the correct application of the methods “QFD” and “TRIZ”. Two aspects have to be considered in this context: Firstly, the **complexity of the methods**, and secondly, the **designers’ experience**.

(1) The complexity of a method can be reflected in the number of required cognitive processes as well as in the length of time needed to apply the method. As displayed in the central column of Table 2, both methods “QFD” and “TRIZ” have more than one single goal. Moreover, these multiple goals require highly different cognitive operations within one and the same method:
The method “QFD” aims at the transformation of customers’ wishes into technical variables and supports operators in detecting interlinkages between those variables. Afterwards, focal points of the development work should be derived. These aims require cognitive processes that compare and integrate information as well as processes that elaborate hierarchical structures within a set of variables.
The aim of “TRIZ” is a further clarification of the problem by detecting undesired side-effects of particular functions. Additionally, this method supports systematic solution finding processes at an early stage. Thus, “TRIZ” requires cognitive processes that integrate information on the one hand and solution finding processes, which obtain further information on the other hand.
Obviously, the methods “QFD” and “TRIZ” demand a greater amount of cognitive effort than other methods, as they are developed to achieve multiple, heterogeneous goals. Considering the facts that the capacity of the human working memory is restricted [25], [20] and that therefore people strive for “saving” their cognitive effort [26], it is not surprising that the students disregarded specific aspects of the two methods.
Another aspect of the complexity of the methods is the duration of application. The application of each of the two methods took six to seven hours in the observed training course. Due to that fact, it is quite conceivable that participants had difficulties holding up their attention at a constantly high level over that long period of time. Additionally, it can be assumed that motivational deficits occurred under these circumstances.

(2) The second variable that has to be discussed is the level of design experience, the operators of the method have. In prior research, design experience has been recognised as an important influencing factor on the design process and its outcome [e.g. 27]. As the participants of the observed training course were novice designers, who indeed had theoretical knowledge about methods but no practical experience in the field of engineering design, they maybe were not able to grasp the whole range of the two complex methods “QFD” and “TRIZ” on the one hand, nor could they transfer their theoretical knowledge to a concrete design case on the other hand.

Overall, trying to explain the results from this study, two factors have to be considered, the complexity of the methods and the designers’ experience. The interplay of these variables is of particular importance, as designers with no or little practical experience in the field of product development seem to have difficulties with the application of complex and demanding methods.

For this reason, implications of these findings for the methodological training course at the TU Munich and for design education in general have to be discussed. What changes could be undertaken in order to gain a better understanding and application of the methods "QFD" and "TRIZ"?

One first measure could be to instruct the student, who works as a facilitator during the corresponding sessions, to point out explicitly the difficulties and demands of the two methods (especially their multiple goals). It also could be helpful if he or she supervised particularly the correct implementation of those aspects of a method that tend to be neglected (see section 5).
Furthermore, it is crucial to reduce the methods' complexity when applying them in a course for novice designers with no experience in the development of technical products. For example, one could decrease the number of elements that are linked to each other in the "House of Quality" or reduce the number of functions, whose side-effects have to be detected during the application of the method "TRIZ". Thereby, the duration of method implementation decreases and the students might be able to concentrate their attention on the complex demands of the method. Certainly, the results of the particular process step are not as meaningful as under consideration of all relevant variables, but the students will get a chance to grasp the complexity of the method and to apply it in a correct way.

Another option could be to apply the two demanding methods "QFD" and "TRIZ" in small groups of two or three persons instead of employing them in a group of ten participants. This could help that every single person has to play a more active role in the problem solving process, which requires their best attention and prevents "social loafing".
As a last measure, an alternative sequence of the methods taught in the training course can be discussed. As Lindemann [4], the author of the Munich Procedural Model (see Figure 1) emphasises, the steps of the design process do not necessarily have to occur in the proposed sequence. In terms of a flexible application of procedural models it would be possible to change the order of the methods employed in the training course with a view to position the more complex and demanding methods at the end of the process. The advantage would be that the students are more acquainted with method application in general when they are supposed to deal with the more complex methods "QFD" and "TRIZ". Concurrently, this option bears the risk that the students can not manage to go off the framework of proposed steps and their recommended order. A flexible handling of design methodology could ask too much of the novices and enhance their feeling of uncertainty instead of supporting them.

7 SUMMARY AND PERSPECTIVES

Overall, it can be summarised that in design education it is not enough only to implement promising educational concepts. It has to be proved whether education in design methods reaches its goals. The reported empirical study intended to evaluate in how far methods taught in a methodological training course were applied in an appropriate manner by the participants and whether the methods supported the required cognitive processes.
Results of the study show that the methodological training offered to graduate students at TU Munich is a useful way for teaching design methods and giving the students the opportunity to practice various methods on a concrete design case. Most methods taught in the course were understood and applied correctly. In order to enable the students to grasp the whole range of the more demanding methods "QFD" and "TRIZ", some measures have to be implemented, which adapt the complexity of the methods to the lacking design experience of the participants.

In future, it is crucial that further evaluative studies assure a high quality of education in design methods, in order to qualify students to deal with the complex demands of product development. Interdisciplinary studies, which combine the different theoretical and methodological approaches [28] from psychology, educational sciences, and engineering sciences, could contribute to that goal.

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