

USER-SUITABLE TRANSFER OF DESIGN METHODS

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1 Introduction

Design methods are supporting tools for designers to plan products, to check tasks in the conception process and to complete the process. Important for the use of methods is their calculated application. Depending on the designer's experiences and situation, the one or the other method will be more suitable for a specific situation. Abstraction power, systematic working, and the ability to reason are necessary to apply them successfully. Designers should be well acquainted with these requirements in method competence. But reality is shown in the following scenario:

There are many design methods in the range of product development. Well known examples in literature are Pahl [1] and Ehrlenspiel [2]. Empirical research reveals that these methods are not applied comprehensively in industry. Gausemeier [3] ascertains that complex methods are well known but only sporadically applied. At this point the question arises, why design methods are not applied despite intensive research during the past 30 years [4]. Schneider [5] noticed in his investigations in industry, that there are shortcomings in respect to applying and teaching methods. A starting point in improving the status of method transfer comes from the psychological and pedagogical perspective. There is a chance to integrate more psychological and pedagogic concepts and findings in this field of product design. In the department product development and machine elements (pmd) at the Darmstadt University of Technology, many research projects have been carried out together with cognition psychologists and industrial companies. In these projects many insights and much knowledge have been gathered for a sustainable transfer of design methods. The focus of this paper is on teaching and to overcome the mental and psychological barriers to learn and apply design methods.

2 Shortcomings in method transfer and teaching

The department pmd noticed gaps in teaching methods. Main problems arise due to some methods' poor applicability. These problems are partly caused by the separation of factual knowledge and process oriented, methodological knowledge in lessons. This division is based on the hypothesis that without knowledge students can hardly design properly, and therefore, a solid foundation of knowledge must be built up before they can work on a design project [6]. Another problem is how this knowledge is presented. So far, there is no didactic concept in the presentation of methods which might support factual and process oriented learning at the same time.

Some problems were determined by professors of mechanical engineering who came together in 1999 to discuss the teaching of machine elements. They recognized the lack of a holistic view of methods in increasingly complex situations in product development. They assert that there is a need for the integration of factual in methodological knowledge to support the ability to apply methods. Further they demand more exercise in overriding

knowledge such as competencies in communication, organization, responsibility and methodology as a prior main thread. This requirements result from the application environment of design methods, like team work, process-orientation, uncertain information, etc. Thus, these problems are not caused by methods themselves, rather in teaching and transferring them to different situations and applying them adequately. Therefore, solutions to these problems will not be found in the field of product development, but in the pedagogic and psychological field.

2.1 Research questions

Up to now, there have been only investigations into methods and their features. With pedagogic and psychological findings human factors can be taken into account when teaching methods. With this knowledge a didactic concept should be developed for teaching methods. Consolidated findings in education and psychology, especially in knowledge psychology and instructional psychology, state that transfer is highly dependant on the presentation of the learning content and the situation [7]. In order to achieve sustainable learning and application of design methods there are three questions which must be answered.

The first question is about human requirements on the learning material. This question contents two aspects. On the on hand it addresses the human characteristics like motivation, perception, etc. and on the other hand it addresses the presentation of the learning material, like layout, structure, etc. Chapter 3 deals with these two aspects.

The second question concerns the design methods. What features are typical for design methods in their role as learning content? More precisely, what are the characteristic problems learning design methods and how they differ from other learning content like mathematics or biology? This question is addressed in chapter 4.

The third question is about the learning situation. How the learning situations influence the learning result and the sustainability? The answer for this question might be found in the different learning theories. Different learning theories are more or less suitable for different learning contents. Thus, there must be found a learning theory or a mixture of learning theories which are most suitable for design methods. This question is considered in chapter 5.

2.2 Dimensions of the learning situation

The three questions can be integrated in a model which outlines the three dimension of the research field. The three dimensions are given by the individual, the design method and the presentation.

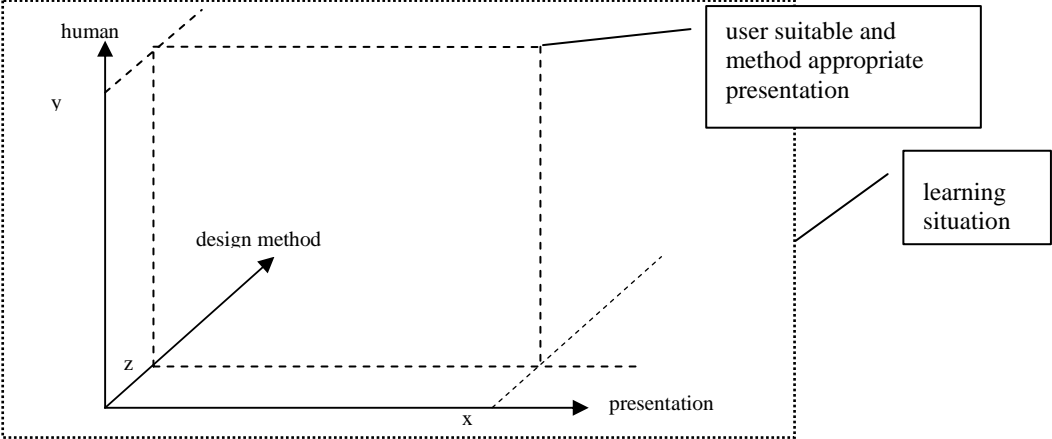


Figure 1: Dimension of learning methods

The learning situation can be understood as the framework in which the three dimensions need to be adjusted. The three dimensions are the individual with its characteristics of learning, the presentation which its property as connector between individual and design method and the design methods it self.

The first dimension is the human one. In first assumptions this dimension is marked by the following attributes: perception, information processing, cognitive conditions, emotional aspects, motivation, etc. It will not be possible to assign values to its attributes, yet. But there is the chance to develop a basic dimension for individual requirements in respect to learning. These requirements can be found in psychological investigations especially in the field of instruction constructivism and cognition.

The second dimension is provided by the methods themselves. Furthermore, in this dimension a chance to divide methods into categories exists. There also exists the possibility of distinguishing between methods, which are more individual or more group-oriented and methods which are more process-oriented or more static. But in this first approach the characteristics of methods as learning content should be investigated. In a later step, it would be promising to establish such categories.

The third dimension is defined by the presentation itself. Presentation has three attributes and a comprehensive description of a presentation is given. The three levels of presentation are considered in chapter 5: the content level, the structure level, and the layout level. These levels provide the possibility to adapted presentations to the human and methods requirements.

Considering human factors and methods only, the question as to how humans learn a method arises. Generally, students learn the methods in lessons, exercises, with books or perhaps with computer programs. Regardless of the medium with which the method is presented, there is the question of which didactic concept lies behind the presentation. How the methods must be introduced in order to guarantee the most effective, comprehensive and correct learning process? To answer this question one must in the first step consider human factors in respect to perception and information processing. In the second step methods need to be analyzed in their function as a learning content. Next, the presentation abilities must be considered in respect to support learning.

3 Human factors

3.1 Mental Models

Learning is not necessarily a transfer of knowledge from teacher to student. It is rather an active process, in which new information is processed and new knowledge generated. The research of learning begins with models which state that new information will be integrated into existing knowledge and built up in a mental model. "Learning from texts requires that the learner constructs a coherent mental representation of the text, and representation be anchored in the learner's background knowledge" [8]. Thus, mental models are an important starting point for illustrating learning materials.

There is no general accepted definition of mental models, but they are all based on the same idea. A mental model is a representation of information, i.e., depicting connections, structures, and processes. Mental models are developed within the learning process.

Humans have the ability to construct models of reality based on visual impressions. The starting point of mental models is the perception and understanding of connections. Mental

models are dynamic; that means with growing understanding of circumstances or processes, the mental models will be adapted. Thus, it will be an advantage in design learning material supporting mental models. It would be sensible to illustrate learning material and enable learners to generate a mental model more easily, which can be extended in the following learning process step by step. In respect to these theories, learning could mean, in the first step, a change of cognitive structures, in the second, a change of behaviour, and in the last, a change of performance.

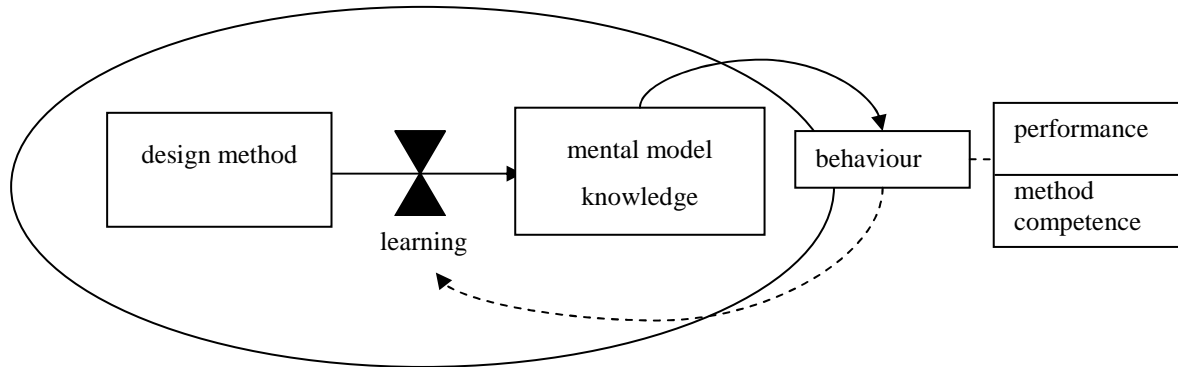


Figure 2: Learning as a change of cognitive structures, behaviour and performance

3.2 Limited information processing

Generally, the human processing of information is efficient; nevertheless, the ability of handling complex and extensive information is limited. If problems require three to four items at the same time, problem solving becomes more difficult and produces poor solutions. Information processing is sequential, which means that just single information can be processed at one time. For this reason information processing takes more time in a complex environment. Therefore, efficient information processing highly depends on an appropriate presentation of information, which considers the requirements of human information processing.

4 Teaching methods vs. teaching knowledge

4.1 Characteristic features of methods

Normally students acquire knowledge in lessons, tutorials, through books or lecture notes. The distribution of declarative and procedural knowledge is normally focused on declarative knowledge especially if it pertains to history, biology, etc. But when students try to acquire knowledge of design methods, they are faced with more procedural than declarative knowledge.

Design methods have a different focus than in other subjects regarding declarative and procedural knowledge. Design methods are very process-oriented, dependable and action-driven. Further, design methods do not have variables which can be inserted as in mathematical formulas. In fact, design methods have variables which must be applied, but it is difficult to identify them. This is caused by the lack of information during the design process and the complexity of situations. For these reasons there is a need of experiences and fundamental process knowledge to apply design methods successfully.

Furthermore, product development represents a complex problem solving process which should be accomplished using design methods. To apply design methods in industry,

designers have to have procedural knowledge about methods, or better, they be competent in applying methods. Solving design problems requires the identification of the design problem, analyzing the problem and applying the best design method for a given situation.

Generally, solving problems requires knowledge about concepts and facts (declarative knowledge) and additional knowledge about strategies (procedural knowledge) in specific ranges. Therefore, design methods require a different didactic concept to teach them adequately. This didactic concept's duty is to teach with a focus on procedural knowledge, or more abstract meta knowledge, acting under uncertain conditions and identifying situations.

4.2 Teaching procedural knowledge

To teach methods one has to take a look at how one learns rules and processes. Rules and processes can be compared to procedural knowledge. Thus, an analogy between learning methods including big parts of procedural knowledge and learning rules and process can be assumed. Therefore rule and process learning gives a starting point for learning methods. The learning of rules and processes can be divided into three steps.

At the start of learning a method, the terms should first be explained. If terms are not known or are known simply in another context, they must be (re-)defined. If a term has different meanings, it must be explained which meaning is assumed in the rule. Only then it is useful to start with the rules.

In the next step it is very important to describe the context of the terms. But it should be avoided that word orders are learned, with no relation between the single words. Furthermore rules can only be learned if terms in presentation can be remembered [9]. Presentation helps prevent this phenomenon, since presentation can illustrate relations, thus making them clearer. Another important point is the consistent use of terms. In summary, requirements of successful rule learning are the knowledge of terms.

In the third step, examples can be used for the holistic explanation of terms and objects. Also, revision of the rule is an important part of rule learning. Various structured exercises can be used to check if a rule is known. Therefore, the learning of procedural knowledge can be divided into three levels:

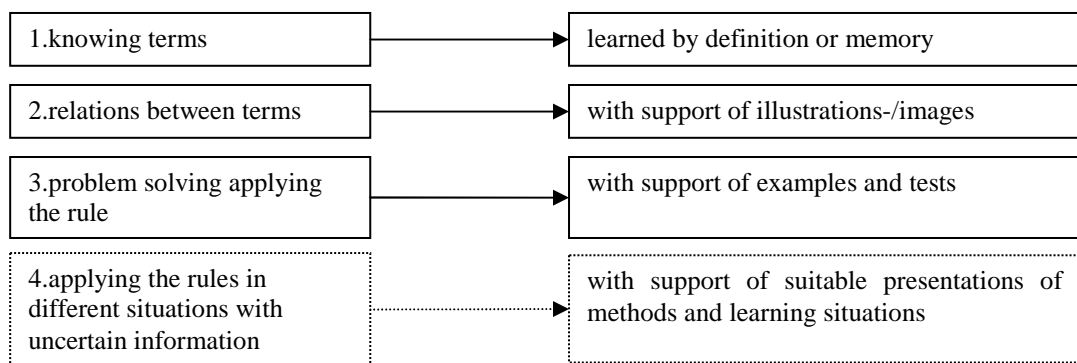


Figure 3: Learning procedural knowledge

Decisive for this procedure is to build on a foundation of existing knowledge, to clarify terms and put them into context. After that, the right application can be encouraged with examples and tests.

A fourth level needs to be developed for methods, to support the addition requirements of methods to rule and process learning. In this level the situation dependency and information uncertainty is considered with adequate presentations and learning situations.

5 Presentations

In general presentations can be divided into three levels. The first level is given by the method's content. It is determined which content is to be presented. On the second level the structure is established. Structure stands for order and hierarchy of the content. The last, the layout level, prescribes the formatting of text and graphics with different sizes and font types, colours, etc. Using these three levels it is possible to describe presentations comprehensively. With their different attributes they provide the opportunity to make the presentation of methods user-suitable.

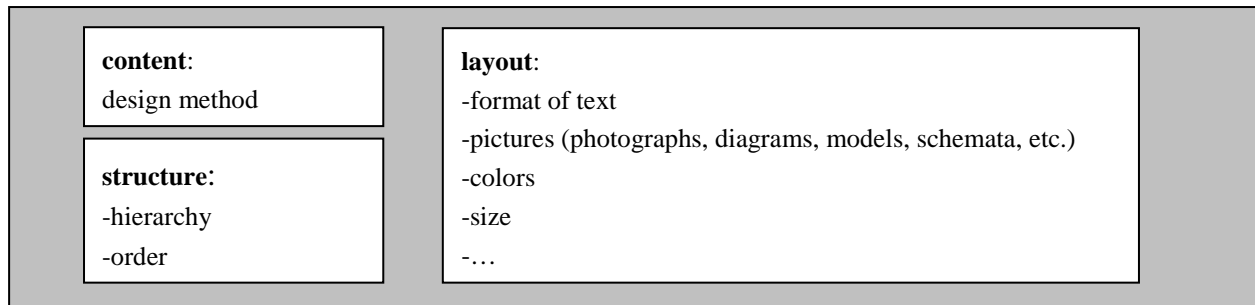


Figure 4: Three level structure of presentations

On the content level one should determine which contents are known and which need to be explained. The same considerations should be made for connections. Furthermore the realization to connect new knowledge with background knowledge should be born in mind.

On the structure level decisions as to hierarchy and order of contents should be made. For example, expressions should be organized in a hierarchical or sequential way. It is also useful to put elements and expressions into a context and make them transparent. This makes it easier for the learning person to find interfaces between existing structures and to integrate new knowledge (assimilation) and accommodate these structures with the environment.

The layout level presents the widest level of varying presentations. At this point it is necessary to define the terms, pictures, and all sub-terms. In the following expositions, pictures complement the terms diagrams, graphics, schemata, etc. The term *illustration* means the combination of text and pictures.

5.1 Effects of illustrations

Illustrations facilitate the processing of information. Reception of a text needs a lot of process capacity. However, cognitive resources are limited; this phenomenon is called 'cognitive load'. The combination of text and pictures facilitates information processing and multimodality assists the generation of mental models. Especially learners in a new field need in the beginning of the learning process a stronger structure and orientation.

Levie and Lenz [10] compared illustrated texts with non illustrated texts and found out that decorative illustrations do not have any influence on the learning effect. A study in 1987 by Levin discovered that images significantly improve the learning effect. An explanation for the fact that pictures are more expressive than texts is given by Paivio [11] with the model of dual coding. In his dual coding theory, Paivio states two autonomous but integrated subsystems in the cognitive system of humans: a verbal system, which processes spoken and written verbal information, and an imaginary system for picture processing. According to Paivio, texts are only processed in the verbal system if an abstract fact is described, that is not imaginable. Pictures found principally dual coding in the imaginary and verbal system.

Also the sequence of presentation has an influence on the learning effect. In 1988 Weidenmann [12] conducted a study in which the text was presented before and after the illustration. Investigations have shown a better learning effect when the pictures are presented before the texts. Generally pictures are remembered for a shorter time when they are placed after the text. This phenomenon is called the “sequence effect”.

5.2 Pictures to support mental modeling

The meaning of pictures is very important. In the following paragraph the function of pictures in the learning process, especially the meaning for human perception and information processing is discussed. There are seven functions of pictures and graphics in the learning process:

- Motivation: pictures make content more attractive, but do not help to understand.
- Advertence: pictures can outline the most important contents
- Situation representing: pictures help to give the learning person a better understanding and picture the situation
- Transformation: pictures support remembering content, especially key information
- Organization: pictures lead to a better organization of connecting contents for the learning person
- Interpretation: pictures support a better understanding of contents
- Emphasize thinking operation, which supports the problem solving process

The aim of pictures is to support the learning person in building up an adequate mental model (mm) of the learning field. This mental model should be as isomorphic to the conceptual model as possible. Considering learning functions, such as information processing in the mental model, it can be also explained as an interaction between the environment and the mental model. This interaction can be supported by instructions. With the aim of aiding the learning person as much as possible, the presentation of methods should take advantage of the positive effects that pictures have.

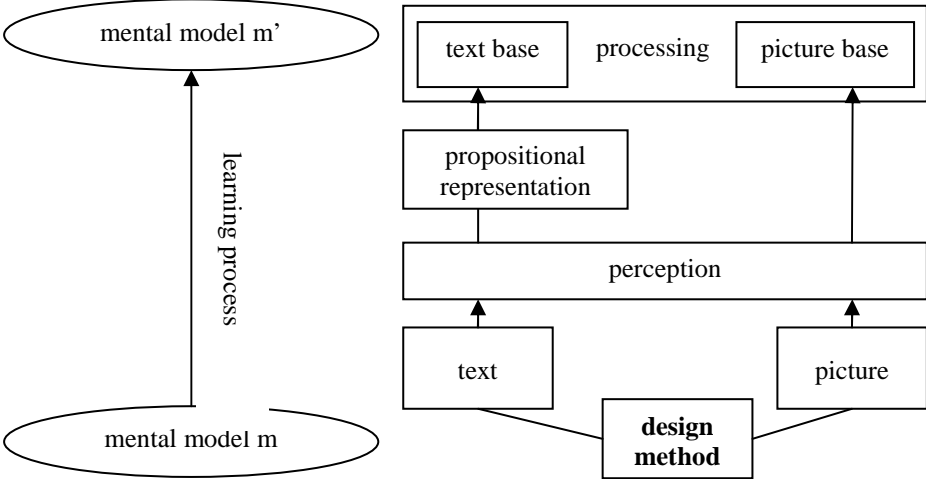


Figure 5: transforming mental models

Methods are presented by texts and pictures in a specific order and with a sensible connection to each other. This presentation is perceived by humans. Pictures are perceived and directly integrated in the mm. Texts, on the other hand, must first be transformed from verbal,

descriptive language into a relevant representation. With this process the mental model m is transformed into the mental model m' .

Basically there are four characteristics of pictures [13]:

1. Complexity of picture organization

Complexity of pictures is measurable by the amount of objects and details. Research has shown that it is more interesting to look at realistic and complex pictures. But this doesn't necessarily lead to a better knowledge transfer. Dwyner [14] found that knowledge transfer depends on complexity and available time. If there is a fixed time for the learning process, simple pictures are more effective than complex pictures. In the case of unlimited time (self-instruction), more detailed and realistic pictures are better for the learning effect.

2. Colour

Colour can increase complexity. However, colour draws attention to specific information, connections or differences. They allow the viewer of the picture to identify different parts and their relations. But colours should be used carefully because the learning person is only able to process a certain level of complexity.

3. Size and Arrangement

The appropriate size of pictures depends on the available period of observation. If there is just a short period of observation, the picture should be big enough to see all the relevant details. Regarding the arrangement, it has to be clear what kind of function the picture should fulfil. To activate previous knowledge, it makes sense to place it in front of the text. It encourages the learning person to continue reading the text. If pictures are placed after the text, they can be useful for repetition and reorganization of already processed information.

4. Type of information

Pictures can contain different types of information. Mandler and Johnson [15] classified four types: textual information, which specifies which objects a picture contains; information about the place of certain object; descriptive information, which specify details of objects and describe their appearance; information about the correlation in space of a picture

Therefore pictures have certain aspects for the learning person: Pictures can influence a person's attitude towards texts. They can supplement important information, and they facilitate human perception. In a combination of text and pictures, dual coding is supported [16]. Furthermore, pictures support the learning of complex relations. Royer and Able [17] demonstrate that pictures have a considerable influence on transfer. In addition, pictures have a great influence on information processing. Gaining new knowledge highly depends on pictures. Also, pictures help modify existing knowledge, and thus, the development of mental models.

6 Learning Theories

There is no general valid definition of learning in literature. Basically, two main streams in psychology are established: a cognitive and a behaviouristic one. Behaviourism considers simple forms of learning. With the learning process in a black box, behaviourism analyzes the connection between stimulus and response. Learning is understood as linking between stimulus and wanted reaction, also known as classic conditioning. Cognitive science has its focus on the intra individual processing of knowledge. Cognitive science assumes a mental

model, which can form new knowledge with already existing structures and embed this knowledge in them (assimilation). In case of contradiction between old and new information, one or the other receives new interpretations to fit the other (accommodation). From cognitive science a constrictive science was developed. This theory improves the cognitive theory especially in that its point knowledge is constructed within the conversation of the learning environment. Individual aspects are outlined, including background knowledge. This theory focuses on the problem solving process, transfer and a holistic way of thinking. For these reasons, this theory seems suitable for learning methods.

7 Conclusion and Outlook

To provide user-suitable design methods, there is abundance of evidence and findings in the pedagogical and psychological research field which can be integrated in the teaching process of product development methods.

Various deficits are identified in Chapter 2, such as the requirements for the process orientation and for meta knowledge. They must be fulfilled with a more holistic approach for a didactic concept for learning methods. To this approach belongs the ability to communicate and to make decisions based on uncertain information, etc.

From these deficits the research questions in chapter 2.1 are deduced, which focus on the three main subjects of this paper: the individual, the design methods and the presentation within the scope of the learning situation. The possible attributes of the three dimensions are exemplified in chapter 2.2. This framework supplies a foundation for the investigation of the three subjects regarding their requirements for a didactic concept and properties to support such a concept for design methods.

A central subject are human factors (Chapter 3). Their requirements must be integrated into a didactic concept. For this, it is necessary to take a deeper look into cognition and information processing of humans. In particular, the requirements of mental models on the learning material of methods must be deduced and identified. Also, human information processing establishes the requirements on a didactic concept and its presentation.

The next subject is the design method itself (Chapter 4). In particular, the characteristics of design methods are: procedural knowledge, process-oriented, flexible, action-led, and situation-dependable. For this, the teaching concept for rules can be enhanced and adapted to these additional requirements of design methods.

The final goal is to present design methods in a user-suitable form which also meets the requirements of methods. For this reason, the possibilities of presentation are analyzed regarding the effects on supportive mental modeling (Chapter 5).

This paper is an approach to overcoming the deficits in teaching and transfer design methods. Such a holistic approach was generated within the “pinngate”-project in the pmd-department at Darmstadt. The main objective of pinngate is to construct a system which supports the learning and teaching of design methods. Flexibility, individuality, adaptability and up-to-date information are the main characteristics of the pinngate-system.

A central point of further investigations in this field will be subjective perception, pattern matching, the influence of experiences on learning processes, and the learning situations. Thus, how the parameters of learning situations and theory influence the pattern perceiving it will be investigated.

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