INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITÉ DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

LEVELS OF EXPERTISE IN PRODUCT DEVELOPMENT – IMPLICATIONS FOR THE DESIGN OF INSTRUCTIONAL MATERIAL

M. Lenhart, H. Birkhofer
Darmstadt University of Technology

ABSTRACT
Printed instructional material is an adequate instrument for the routine imparting of subject-matter content. Textbooks are usually written for a broad spectrum of users, covering students as well as industrial designers. Learners in product development are, however, very different in regard to their individual knowledge, experience and educational background. Universal documents try to meet all readers' requirements, which is almost impossible.
In this paper, the cognitive load theory is used to illustrate that a great variety of different scenario-specific documents is essential for an effective acquisition of knowledge. The theory is transferred to concrete examples considering the special nature of product development and the description of design methods. Moreover, specific recommendations for the design of reader- and situation-specific instructional documents are derived. These recommendations refer to the document's design elements such as text quality and quantity, text structure, coherence, illustrations, examples, tasks, etc.
An empirical study with 168 students showed that the way in which contents are presented can have a significant impact on the results of method application. The study gave implications that conventional learning documents are lacking in the direct transfer of knowledge to concrete situations. Readers using optimised documents showed significantly better results.

Keywords: cognitive load theory, expertise, instructional material, knowledge transfer

1 INTRODUCTION
In contrast to science and the humanities, the domain of product development knowledge is characterised by complexity and ill-structuredness. Accordingly, development problems are usually poorly defined and structured [1]. In most cases, the problem-solver does not have all the necessary information and there is no guarantee that a correct or ideal solution will be found. Moreover, problem-solvers display very different characteristics regarding their individual knowledge, experience and educational background. These individual characteristics have to be considered during the educational transfer of product development knowledge.
To ensure an effective and efficient knowledge transfer, user-specific learning documents are strongly required. These documents should have a specific content, structure and layout. The learner's level of expertise, especially his/her level of prior knowledge, plays a decisive role in the design of instructional material [2].
Today, most standard works of product development literature (e.g. [3], [4]) are written for a broad spectrum of users, covering students as well as industrial designers on different knowledge levels. As printed literature is a static medium, user-specific requirements in regard to the preparation and presentation of contents can only be considered to a limited degree. As a result, different documents for different target groups in various situations should be created.

2 STATE OF RESEARCH

2.1 Design of Instructional Material
Regarding cognitive learning theories, learning is defined as the acquisition of knowledge and skills [5]. According to Jenkin's tetrahedron-model [6], the success of a learning process is strongly influenced by four fields: the learners' characteristics, the characteristics of the instructional material,

the way of cognitive processing and the learning goals (cf. Figure 1). In practise, the material's characteristics play a decisive role in the support of a durable, successful learning process [5]. It is the only field that can be directly designed and modified. However, the other three fields have to be regarded as well because all fields strongly interact with each other and should have a special influence on the optimal design of learning documents. For the authors, the fields of learner characteristics, cognitive processing and learning aims are predetermined. The major challenge is to derive requirements for an optimal document from these external factors.

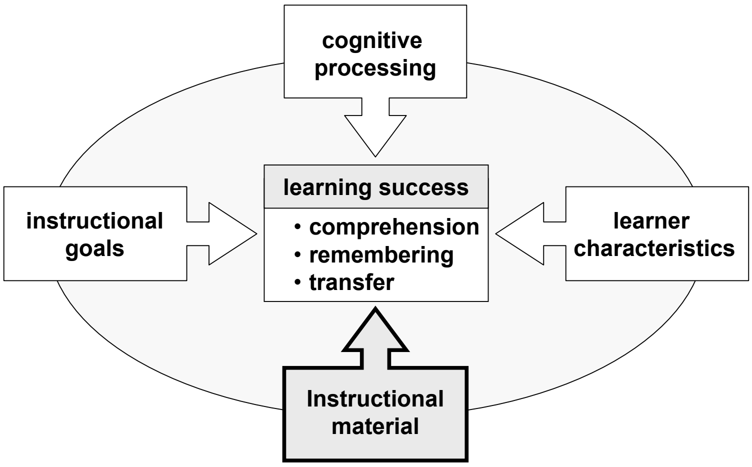


Figure 1. Factors influencing the learning success

A successful learning process implies remembering, comprehension of the learned contents and transfer to real-world situations. Within this context, the transfer must lead to active doing (application). *Comprehension* is an ambitious goal. It covers two perspectives. The content perspective refers to the acquisition of what is displayed on the document. In contrast to that the relation perspective refers to the meaning of contents. In this connexion, the reader analyses and assesses the meaning of what is displayed. *Remembering* is closely connected with comprehension. Comprehension alone is not a sufficient condition to embed knowledge in the long term memory. Additional processes of memorising and training are necessary. These processes can be supported by instructional material at least to a certain degree. Support is given, for example, by elements that activate prior knowledge, repeat relevant content or provide control questions [5].

The development of problem-solving skills is definitely one of the most important goals in product development education. Therefore, knowledge transfer has to facilitate the learners' abilities to use their knowledge in such a way that it can be transferred to new situations and new development problems.

In many cases, education leads to 'inert' knowledge that can be verbalised but not transferred and applied. To create an effective learning document about a development method description, it should

- *support comprehension* by putting the method into perspective of the development process, describing prerequisites/ barriers of application, etc.,
- *enable the reader to retain the central facts* (concepts, procedures, sequences) and
- *provide information relevant to practise* (transferability to concrete situations).

These recommendations refer to didactic design. The discipline of didactic design deals with the transfer of cognitive science to the practice of how to design learning environments. In this connexion, it can be seen as a kind of applied cognitive science. Its aim is to develop guidelines for an optimal design of texts and pictures according to cognitive theories of human information processing. Within this context, the preparation and presentation of contents must not inhibit the acquisition of information in any way but should support it.

According to Ballstaedt [5], the design of printed material has to consider three basic principles:

Functionality: The designer of instructional material has to put emphasis on the particular function of knowledge transfer. Accordingly, functionality should correlate with the special learning goal. In this regard, motivation and stimulation have to be considered as well.

Convenience: The material design should reflect a reduction to the very essential didactical principles. Dispensable or even obstructive additional content has to be deleted as far as possible.

Consistency: This principle reflects didactic means, like phrasing, the relative position of text and pictures, the use of colours, etc. They have to be implemented in a consistent and definite way. In other words, a once set standard should not be changed within the same document.

Ausubel [7] noticed that printed material is an adequate instrument for the routine transmission of subject-matter content. Its advantage is based on the fact that the learner can control the quantity of material being presented in a given unit of time as well as the rate of presentation. Hence, readers can pace themselves in accordance with their intelligence, reading skills and the complexity of the subject matter. It is possible to take as much time as one wishes to savour the language, reflect upon the content and relate it to other relevant ideas. This should be valid for a computer-based content presentation as well. Ausubel also emphasised, that deficiencies often ascribed to printed documents are not really inherent in the medium itself, but reflect shortcomings that are common to all inadequately prepared instructional materials such as:

- lack of lucidity,
- ineffective communication,
- inappropriate level of sophistication and
- absence of explanatory and integrative ideas.

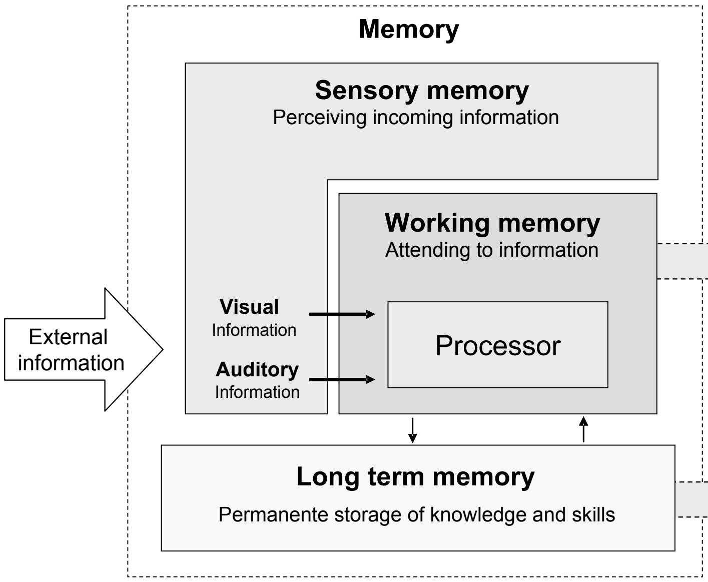
To improve printed documents, it is useful to take into account considerations such as progressive differentiation, integrative reconciliation, sequence of subject-matter content and the use of (advanced) organizers. Even though printed documents can contain some built-in adjunctive feedback and evaluative devices, it is very difficult to integrate elements that stimulate and guide the readers' independent study, thinking and problem-solving activities. From this it follows that the teacher plays a decisive role even when documents are optimised according to the described guidelines. The teacher is responsible for such matters as differential practice, prompting and coordinating the documents with lectures, exercises, audiovisual aids, supplementary literature and independent learning projects [7].

2.2 Cognitive Load Theory

The cognitive load theory (CLT) has important implications for the design of instructional material. It describes an information processing model of cognition, which emphasises the inherent limitations of working memory. It uses schemas as the relevant unit of analysis and gives specific implications for the design of instruction [8], [9].

The cognitive load theory is based upon a three memory storage system. It contains a sensory memory, a working memory and a long-term memory. The sensory memory is used to perceive incoming information. This information is either visual or auditory. The long-term memory is used to permanently store knowledge and skills in a hierarchical network. It has an almost unlimited capacity. It is supposed to be the driving force behind all skilled performance. Regarding the CLT, the working memory plays a decisive role. It is used to attend to information und enables us to think logically as well as creatively [10]. In this regard, the working memory supports us in solving problems and being expressive. In contrast to long-term memory, its capacity is limited to fewer than 9 items of information. In the context of the CLT, the limitation of working memory is a crucial factor for the optimal design of instructional material [9].

Regarding this model, readers on different levels of expertise differ especially in number, size and the cross-linking of schemas stored in long-term memory. Novices usually possess a small number of schemas that are hardly cross-linked. By contrast, experts in a specific knowledge domain have a large number of big schemas that are highly interconnected [11].



COGNITIVE LOAD = Σ	
+ intrinsic	→ domain complexity
+ extraneous	→ instructional material
+ germane	→ elaboration, efforts

	Novice	Expert
Number of schemas	small	great
Schema size	small	expansive
Degree of inter-connectivity	isolated	highly inter-connected

Figure 2. The modal model of memory

According to this model of cognition, learning is considered to be an encoding process, i.e. knowledge and/or skills are stored in long-term memory in such a way that they can be recalled and applied on demand at a later time. As the working memory is decisive for encoding incoming information, it plays a decisive role in the learning process.

Cognitive load is supposed to be the central parameter that influences knowledge acquisition from instructional material. The concept of cognitive load refers to the total amount of mental activity imposed on working memory at an instance of time. The learning process requires working memory to be actively engaged in the comprehension of incoming information. It encodes the to-be-learned content into long-term memory. Within this concept, the major influence on cognitive load results from the size and number of content elements that need to be attended to. If working memory resources are exceeded, learning will be inefficient and ineffective. Accordingly, the major goal of instruction is an optimisation of schema construction and automation by reducing the working memory load [8].

The CLT differentiates between intrinsic, germane and extraneous cognitive load. *Intrinsic* load is directly connected to the inherent complexity of an idea or a set of concepts. It reflects the difficulty of the concepts and is unchangeable by means of instructional design. In contrast, *extraneous* load can be manipulated to some extent. It covers unnecessary load that can be found in inefficient instructional designs. This type of cognitive load bears little relation to the schema construction process. *Germane* load considers the degree of effort involved in the processing, construction and automation of schemas. It can also be manipulated. The total amount of intrinsic, germane and extraneous load reflects the total cognitive load on the working memory and is essential for an effective learning process [9].

Accordingly, one and the same document could induce different amounts of cognitive load on different readers. The amount of cognitive load is especially dependent on the readers' levels of expertise that reflect the individual level of prior knowledge, i.e. differences in number, size and degree of interconnectivity of schema.

From this it follows that, in general, one specific document could support the learning process of a novice in an optimal way (cognitive load < mental resources), while inhibiting the learning process of an expert (cognitive load > mental resources) and vice versa (cf. Figure 3). This could be caused by a document that is adapted to novices' requirements. It leads to an enormous extraneous load for the expert. For instance, the document could contain information that enables the novice to elaborate the content, but reduce the expert's attention, as he is already familiar with the described information. In this situation, the expert's mental resources are stressed to no purpose.

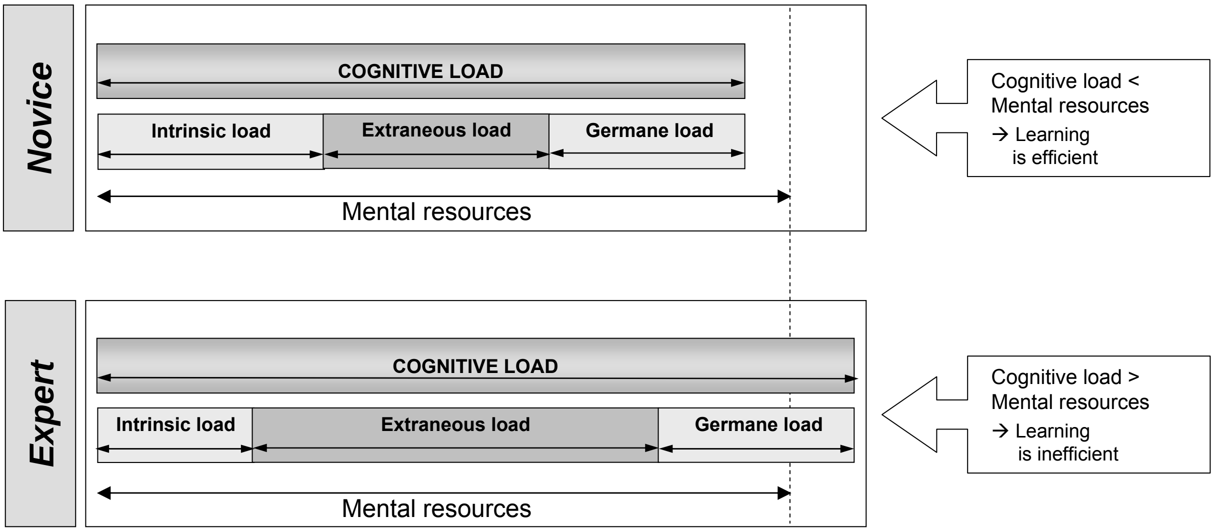


Figure 3. Cognitive load caused by a learning document for novices

3 DEFICITS & RESEARCH QUESTION

In the past, research dealt primarily with technical aspects of the use and reuse of electronic content. Questions regarding the design of user-specific documents were not answered satisfactorily. System-centred instead of user-centred approaches played a major role. Knowledge about the reader’s requirements, which vary due to different levels of expertise, is still lacking. In this paper, the authors apply implications of the CLT to documents concerning product development.

The findings derived from cognitive science just lead to universal, unspecific recommendations for instructional design. The special requirements of product development are hardly considered. For example, the success of a learning process is mainly measured by the learner's ability to solve development problems. Hence, the acquisition of procedural knowledge concerning development methods and methodology is a matter of special importance. Specific guidelines are missing.

In addition, specific recommendations regarding the different learner characteristics are lacking. That means especially readers on different levels of expertise. As there is no general concept of expertise that sufficiently covers all knowledge domains, the special aspects of product development have to be integrated. In this context, general as well as product development-specific guidelines have to be transferred to the design of documents.

Moreover, different reading situations and instructional goals have to be considered. It’s quite obvious that one specific document cannot support a learning situation and a situation in which a concrete design task has to be solved to the same extent. As a result, different users within different reading situations have to be supported with different specific documents.

In this paper, essential characteristics of instructional materials as well as important user characteristics are identified and related to each other. Especially the readers’ specific expertise should be used to derive guidelines from the CLT. These guidelines will refer to the design of printed instructional material that supports the learning and application of product development methods.

4 CHARACTERISTICS OF INSTRUCTIONAL MATERIALS

4.1 Recommendations for contents and text structure

Conventional printed instructional materials for product development (text books, lecture notes ...) generally contain text fragments, different types of illustrations and examples or exercise tasks. In the following, parameter values of these basic document elements will be introduced and discussed. In doing so, user-specific recommendations will be derived.

Text content can be classified according to its function within the process of knowledge transfer [5]:

- *Expository texts* describe facts, i.e. they verbalise complex concepts and relationships and help the reader to expand his declarative knowledge. That means especially definitions, explications and argumentations. Within the description of a development method, they can e.g. describe prerequisites and contexts of method application.

- *Narrative texts* report about sequences, especially of finished actions and events and inform about situations, motives, decisions and their consequences. As in product development active problem-solving and prescriptive procedures are essential, this type of content should be secondary.

- *Instructing texts* verbalize procedural knowledge. They present detailed information about method application (e.g. why, when, how to apply). This content type is indispensable for documents dealing with product development, as the acquisition of procedural knowledge structures is a major learning goal. In addition, the results of method application that should be improved by supportive instructions are a major criterion for measuring the success of a development process.

- *Didactic additional texts* supplement the text with didactic elements to stimulate and support specific learning processes. These include the description of learning goals, control questions, summarisations, and advanced organizers. In this connexion, exemplary descriptions of products and method applications can be integrated.

To provide optimal support for learning and application, documents should contain a specific proportion of expository, instructing and didactic additional texts (cf. Figure 4). In product development narrative texts could be used as didactic additions, but in general they should play a minor role, as prescriptive procedures take centre stage. The proportion should be dependent on the specific situation, its instructional goals and the user's characteristics, including his prior knowledge and cognitive processing.

In the method application situation (i.e. a concrete problem has to be solved immediately supported by a just-in-time presentation of contents), didactic additional texts have to be eliminated. In regard to this situation, the result of method application is more important than long-term knowledge acquisition. The direct transfer of the presented content is a major goal. Accordingly, the document has to be structured considering the sequences of application. In this regard, instructing texts have to dominate content and structure. Expository texts are just used to complement and illustrate the method instructions.

Apart from these content types, a user-specific document depends on a systematic design of the content's coherence. The degree of coherence is a major characteristic of texts. It reflects the quantity and relation of different text or content fragments and is especially dependent on the reader's background knowledge. A gap in the readers' knowledge base has to be compensated by a higher coherence. As novices have a lower level of prior knowledge, they have to be provided with the highest possible coherence. According to this, a document for novices should be extended in regard to the quantity of content. In contrast, a document for advanced learners or experts should be shortened considering the broader knowledge base (cf. Figure 4).

The CLT suggests that a low coherence causes a high cognitive load for the novice. For him, low coherence initiates search processes to create the necessary conditions for knowledge integration [11]. Due to the fact that mental resources could be exceeded, the learning process could be inhibited. Hence, the novice needs documents with a high level of coherence and high content quantity. In contrast, the advanced learner benefits from a low level of coherence, and as a result, from low quantity. A high level of coherence would result in a situation where information is presented with which the reader is familiar. However, information redundant with the readers' knowledge base would raise the level of cognitive load. The readers' mental resources for learning and problem-solving could not be used effectively.

Figure 4 summarises the above requirements and gives recommendations for the text design, considering the readers' level of expertise as well as the reading situation. The size of the columns represents the content's quantity and correlates with the document's coherence.

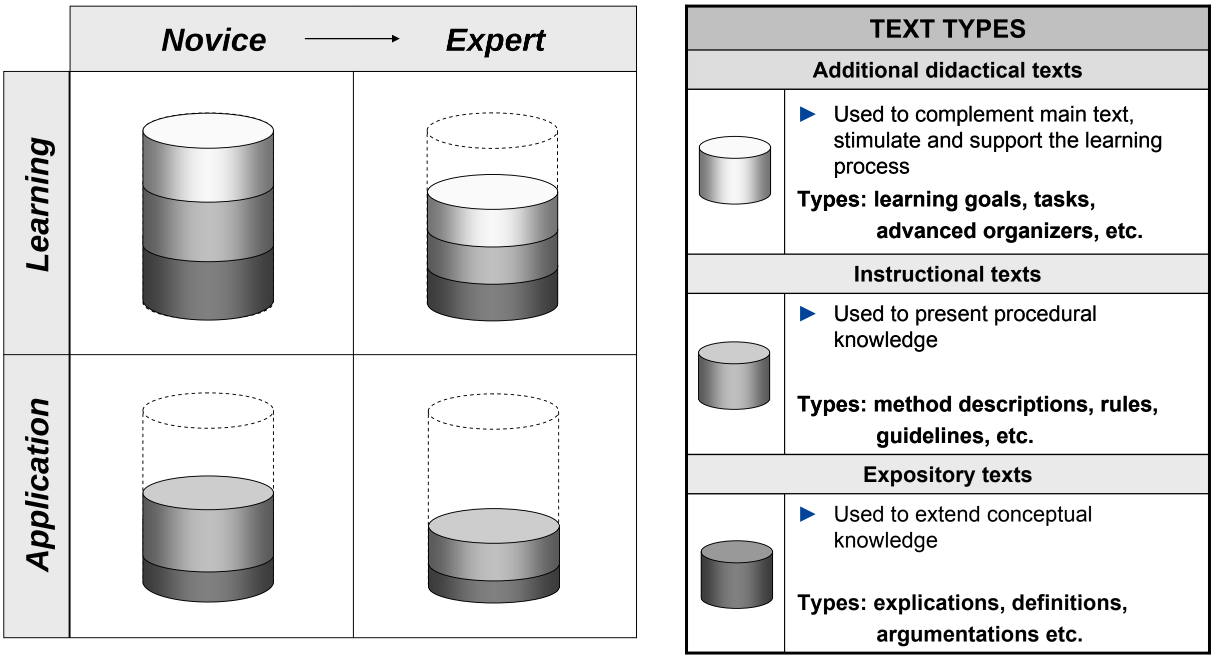


Figure 4. Constitution of scenario-specific documents

Another important characteristic is the document's text linearity. The extent of linearity describes the number of different reading paths that the learner can take. Printed texts are considered to be linear, whereas hypertexts provide the opportunity of nonlinear or at least multi-linear access to contents. As this paper refers to printed instructional material, a linear content structure is assumed to be the object of research. However, it is assumed that multi-linear documents are an ideal medium for experts, as they are free to decide which content is of special interest and which should be skipped due to redundancy reasons [11]. As a result, multi-linear documents reduce the experts' cognitive load by reducing the access to redundant, familiar knowledge. In contrast to that, novices benefit from linear guidance, as their schemas for navigation are still lacking. In this case, linearity relieves the novices' mental resources and provides guidance, which is very important [12] However, multi-linear (hypertext) documents can also be used to instruct novices, if a suitable concept for an orientation guide is provided, e.g. site-maps, tables of contents, marginalia, advanced organisers, summaries, indexes, glossaries, etc.

4.2 Recommendations for illustrations

As the central concern of engineering design is the conception and realisation of new or at least improved products, illustrations and pictures of all kinds are essential elements in the design of instructional material. Illustrations are the most precise and concise way to describe real or virtual objects. Especially pictures of product examples, product models and illustrations of (partial) solutions or procedures are of particular importance.

Normally, pictures do not contain all the necessary information that leads to a deeper understanding of what is illustrated. As a result, pictures have to be explained or at least complemented by additional textual or verbal information. Regarding product development methods, especially illustrated work steps and associated pictures of partial solutions have to be explained and taken in context. Otherwise the reader can hardly obtain a coherent knowledge representation.

Considering the concept of cognitive load, an optimal textual description of a picture also depends on the readers' individual level of expertise [11]. The quantity and quality of additional textual information mainly depends on the readers' prior knowledge, e.g. knowledge about the illustrated product or method.

The parallel use of textual and graphical information describing the same issue is generally supposed to support comprehension. In fact, textual information can also be counterproductive, if redundant information in regard to the readers' knowledge base has to be processed.

Textual additions are usually integrated in the text next to the illustration. This leads to a spatial separation of graphical and verbal information. The readers' cognition has to integrate the different content sources in one single representation. This can be associated with costly cognitive processes.

According to the CLT, these search and match processes interfere with constructing integrated schemas [11]. Regarding novices, the textual description of illustrations should be integrated in the picture itself. Hence, special search, match and integration processes between textual and graphic information are no longer necessary. This way the reader can reduce cognitive effort while concentrating on comprehension and elaboration.

For experts, the separation of text and figures within a linear document is usually unproblematic. This could be due to the fact that an expert is able to recognise and process larger information patterns. This way cognitive efforts are reduced and sufficient mental resources can be used for text-figure integration and schema construction, i.e. the learning process. However, redundant information can cause an additional cognitive load. Thus, it appears that for experts textual additions describing the figure are not absolutely necessary for understanding and must be eliminated as much as possible.

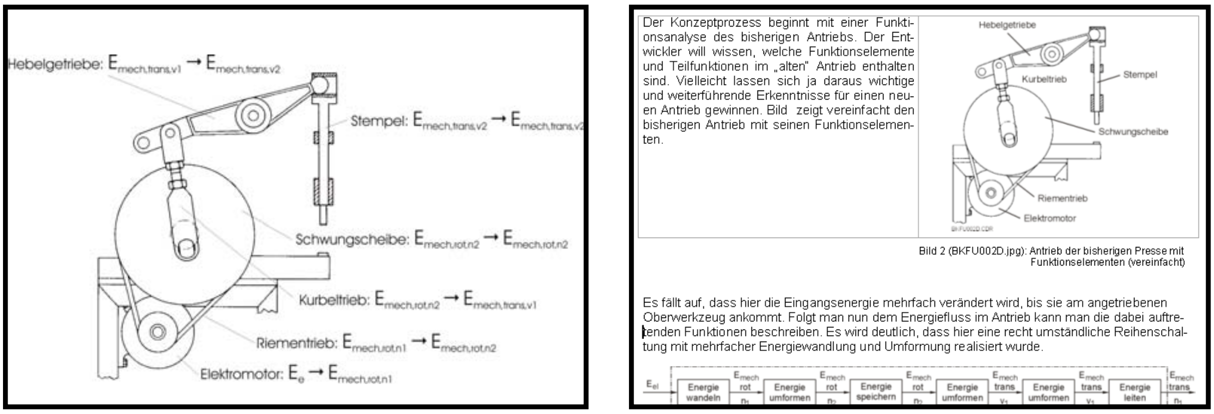


Figure 5. Fragments of instructional material for novices (left) & advanced readers (right)

Figure 5 shows an example of figure design within a document made for novices (left) and for advances readers (right). It shows the drawing of a squeezing machine used to fasten press studs on textiles. It represents a fragment of an instructional document showing the initial situation of a function analysis.

As novices should have difficulties in recognising the relevant components with their corresponding function, the occurring energy transformations are displayed and assigned to the related components. That way textual information is integrated within the figure.

As advanced readers should be able to identify the relevant components and their energetic function, this information is eliminated from the figure and integrated in the main text by an abstract description. This allows the reader to concentrate on the following method description. For a less advanced reader it could be necessary to integrate a more detailed description of the product before explaining the further proceedings.

4.3 Recommendations for the design of examples and tasks

Tasks within instructional material should support the reader to elaborate and transfer the presented contents to new situations. In addition, they should enable the reader to control the success of knowledge acquisition.

Learning must not be a process of solely memorising content. Moreover, the learning process should not end up in a routinised and automatic application of knowledge. Otherwise, problems in transferring the knowledge will certainly occur. As product development is a strongly case-based domain, dealing with tasks, exercises and examples are very important. This paper focuses on the design of method descriptions. Accordingly, the following paragraph will focus on how to design appropriate method tasks for printed instructional material. These tasks consist of the different content elements that can be combined in different ways. There are three major elements [13]:

- *Given state*: It forms the initial situation for the application of a development method.
- *Goal state*: This element describes a set of criteria representing the solution space. Usually different solutions are acceptable.
- *Partial solutions*: These elements represent partial solutions and work steps of method application.

A systematic combination of these elements leads to different types of tasks [13] (cf. Table 1). In the following, only those types relevant for product development are described:

Conventional problems represent typical product development problems. They contain the given state,and a set of requirements about the goal state. The solution has to be developed by the learners themselves. This task can include the application of a single method as well as of the whole design methodology. The learner has to start from the development problem without any further information supporting the problem-solving process. For novices, learning and performing conventional tasks are different and incompatible processes. For them, this type of problem results in a high cognitive load due to the weak problem-solving methods. It is very costly in regard to working memory capacity. As a result, this type should not be integrated in documents that are specially designed for novices or even laymen, as these readers are coming in contact with such issues for the very first time.

Worked-out examples additionally contain an exemplary solution and all work steps including every partial solution. For novices, they result in a low extraneous load as they can focus their attention on problem states and associated solution steps. These tasks enable the learner to induce generalised solutions and schemas. However, worked-out examples can be useless, as learners are not forced to study them carefully. Additionally, they could imply high mental efforts for advanced readers, as there will be redundant information in regard to the learners' knowledge base.

In contrast to worked-out examples, *completition tasks* only contain a selection of work steps and partial solutions. In this way, the instructional advantages of conventional problems and worked-out examples are combined. The reader is directly encouraged to be active. The extraneous cognitive load is also reduced to a bearable extent. Regarding the transfer of development methods, a description of (different, alternative) work steps and partial solutions should be kept to a minimum. Otherwise the learner would not be actively involved.

In other domains apart from product development, "goal free tasks" (no description of the favoured goal state) and "reverse tasks" (developing a problem by starting with a solution) are recommended [13]. For development methods, these tasks should be inappropriate as the domain is strictly goal-oriented and the procedures reflect a characteristic sequence of problem-solving.

Table 6. Tasks for instructional material

Task	Problem state	Work steps	Final solution
Conventional problem	given	→ find	→ find
Worked-out example	given	given	given
Completition task	given	incomplete → find	given

It is important to note that a supported feedback has to be provided. The learner must have the opportunity to assess the quality of his solution. The great variety of possible solutions, that is characteristic for product development, makes it almost impossible to prepare an appropriate feedback for instructional material. This fact alone proves that a (good!) teacher can not be replaced by any kind of document.

The above description of tasks shows that there is no single type for all levels of expertise. Increasing expertise directly results in different requirements. Instructional material for novices should start with worked out examples to support a basic schema construction about the operations. With increasing knowledge completion tasks should be provided. In this context the number of described partial solutions should be gradually decreased, ending up with conventional problems. As those problems play a decisive role in the domain of product development, they should be introduced – compared to other domains – quite early. Otherwise the learners' problem-solving skills would not be supported effectively.

5 EMPIRICAL STUDY ON SCENARIO-SPECIFIC DOCUMENTS

The recommendations described in this paper were derived from the cognitive load theory. They have led to the assumption that the process of knowledge transfer and application can be enhanced by a scenario-specific design of instructional material. The central question is: "Do these scenario-specific documents provide a better support within the process of knowledge transfer?" In this context, the degree of enhancement is of special interest to the further development of instructional design guidelines.

According to this, some of the above recommendations were examined by a first empirical study. This study focused on the *situation of method application*, i.e. a situation in which the user has to transfer the presented knowledge directly to a concrete task or development problem. To this purpose, three groups of novices were faced with a concrete product example (compulsory mixer, cf. Figure 7). Each participant had to apply the method of function analysis and variation to improve or just to simplify the system of energy transformation.

No participant was familiar with establishing function structures, as lectures just started a few weeks earlier. However, they all had attended lectures about the task clarification and had a general idea of product development methodology. Three groups of novices with different documents were examined:

- GROUP 1 (53 participants) → conventional document: designed for a learning and application situation, considering a broad spectrum of readers on different levels of expertise.
- GROUP 2 (55 participants) → learning document: designed for novices considering requirements for long-term knowledge transfer, but not for direct application.
- GROUP 3 (55 participants) → application document: designed for novices within an application scenario.

All document types contained the same amount of relevant content and information. The document design especially differed in the type of text content (proportion of expository/instructional fragments), in the structure of contents and in the preparation of illustrations and examples. All participants had 1 hour to solve the task. Simultaneously, they studied their specific document to obtain all the necessary information about the method and then transferred it to the concrete situation.

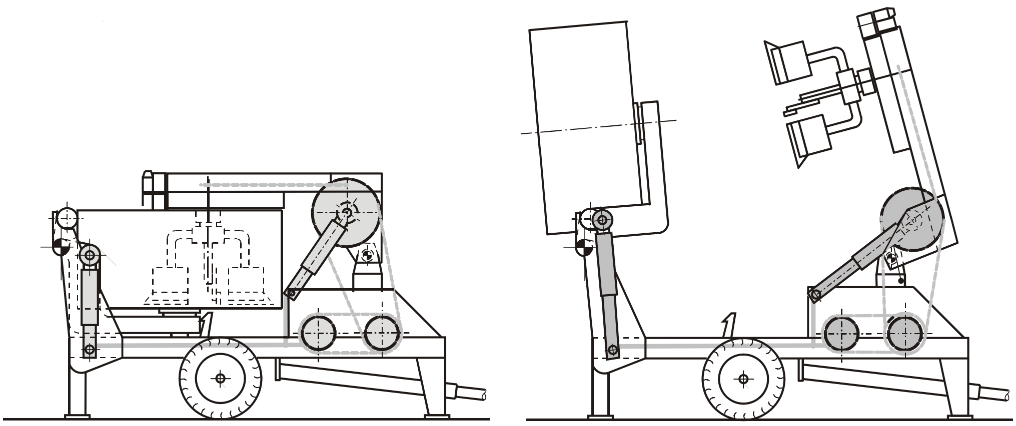


Figure 7. Compulsory Mixer

The results of all participants were analysed on the basis of a standardised evaluation scheme. The developed functional structure was evaluated according to the following criteria:

- completeness of sub-functions
- correctness of sub-functions
- correctness of logical interconnections
- feasibility of variation

After finishing the task, all participants had to answer a standardised questionnaire. The questions were represented by statements that had to be rated on a scale from 5 (full agreement) to 1 (total disagreement). The questionnaire covered the participants' subjective impressions on:

- quantity of text and number of figures
- quality of text and figures
- structure of contents
- self-assessment of the participant

On the one hand, the collected data could provide an indication of the quality of task results; on the other hand, the questionnaire had to provide detailed information about the readers' impression concerning the document. By this means, a first rough evaluation on learning and transfer efficiency as well as on the acceptance of the specific material could be made.

Regarding the average score (cf. Figure 8), the quality of the task results did not vary significantly among participants of groups 1 (unspecific learning document) and 2 (specific learning document). Remarkable differences however occurred within the two groups. In group 1, the total score varied significantly more than in group 2. Accordingly, participants of group 1 should have more difficulties in extracting the necessary information. Participants of group 3 achieved a much higher average score than the other two groups. This result could provide a first indication that documents with a process-oriented structure of mainly instructing text fragments are more suitable for the situation of direct knowledge application. This could be underlined by the fact that there where fewer results with lower scores.

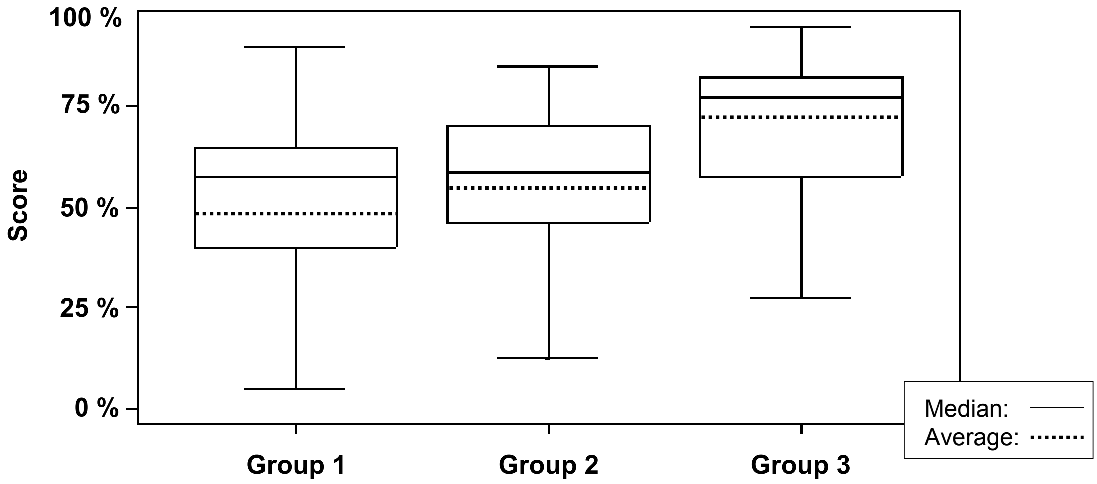


Figure 8. Box plots of task scores

The participants' subjective impressions also varied significantly concerning the following facts: The readers of group 2 and group 3 considered their document to be much more suitable to solve the task than participants of group 1. This is remarkable as the readers of group 2 did not have significantly better results than group 1. Obviously, the optimised learning document and the specific application document were more widely accepted, even though document 2 did not provide optimal support. In addition, participants of groups 2 and 3 felt better prepared to solve similar problems in the future than participants of group 1.

6 CONCLUSION AND OUTLOOK

Learners in product development are very different in regard to their individual knowledge, experience and educational background. As a result, readers on different levels of expertise have very different requirements in regard to instructional material. In addition, the material has to be adapted to the specific situation in which it is used. A learning situation and a situation of direct knowledge application have very different characteristics. For that reason, it is almost impossible to create universal documents that support all potential readers and situations effectively. Instead, a great variety of different documents has to be created. These documents must be designed according to very different requirements.

The cognitive load theory contains a suitable model to illustrate the above statements. It is an appropriate instrument to derive scenario-specific requirements considering the readers' needs as well as the situation’s basic conditions. In this context, several recommendations concerning the central elements of document design (text, figures and tasks) were developed.

By introducing a situation of direct knowledge application, it is possible to design method descriptions that support the direct transfer to concrete situations more effectively. According to the empirical study, conventional learning documents do not support the reader in an optimal way. Readers with especially adapted application documents were more successful in solving the task. As a result, it is important to note that user as well as situation-specific documents have to be created. A lack of specificity is supposedly one major reason for the poor acceptance and rare use of instructional material.

The developed guidelines must be seen as a basis for further research on user requirements. In future, these guidelines have to be transferred to computer-based material, as this becomes more and more important in the acquisition of knowledge. However, most of the recommendations should be directly transferable to a computer-based presentation. Furthermore, computer-based systems should be used to reduce the efforts of creating documents. It was assumed that a great variety of documents has to be created. As the creation is very time-consuming, an appropriate computer-based support is essential.

REFERENCES

[1] Cross N. *Designerly Ways of Knowing*, 2006 (Springer, London).

[2] Lenhart M. and Birkhofer H. Classification of Users in the Context of Knowledge Transfer in Product Development. In *Proceedings of the 9th International Design Conference*, DESIGN 2006, Vol. 2, Dubrovnik, Croatia, 2006, pp. 1187-1194.

[3] Pahl G., Beitz W. *Engineering Design: A Systematic Approach*, 1996 (Springer, London).

[4] Hubka V., Eder W.E., *Theory of technical systems: A total concept theory for engineering design*, 1988 (Springer, Berlin).

[5] Ballstaedt S.-P. *Wissensvermittlung*, 1997 (Beltz, Psychologie-Verlags-Union, Weinheim).

[6] Jenkins J.J. *Four Points to remember.* In Cermak L.S. and Craik F.I.M. (Eds.), Levels of processing in human memory, pp. 429-446 (NJ: Erlbaum, Hillsdale)

[7] Ausubel D.P. *Educational Psychology: A Cognitive View*, 1978 (Holt, Rinehart and Winston, New York).

[8] Chandler P., Sweller J. Cognitive Load Theory and the Format of Instruction. *Cognition and Instruction* 1991, 8(4), pp. 293-332.

[9] Cooper G.A. *Research into Cognitive Load Theory and Instructional Design at UNSW*. http://www.arts.unsw.edu.au/education/clt.html

[10] Paas F., Renkl A., Sweller J. Cognitive load theory and instructional design: Recent developments. *Educational Psychologist*, 2003, 38(1), pp. 1-4.

[11] Kalyuga S., Ayres P., Chandler P., Sweller J. The expertise reversal effect. *Educational Psychologist*, 2003, 38(1), pp. 23-31.

[12] Kirschner P.A., Sweller J., Clark R.E. Why Minimal Guidance During Instruction Does Not Work. *Educational Psychologist*, 2006, 41(2), pp. 75-86.

[13] van Merrienboer J.J.G., Kirschner P.A., Kester L. Taking the Load Off a Learner's Mind: Instructional Design for Complex Learning. *Educational Psychologist*, 2003, 38(1), pp. 5-13.

Contact: Marko Lenhart
Darmstadt University of Technology
Department of product development and machine elements
Magdalenenstraße 4
64289 Darmstadt
Germany
Phone: +49 6151 16-3383
Fax: +49 6151 16-3355
e-mail: lenhart@pmd.tu-darmstadt.de
URL: www.pmd.tu-darmstadt.de