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A CONCEPT FOR USER-SPECIFIC COGNITIVE FLEXIBILITY-HYPERTEXTS IN PRODUCT DEVELOPMENT EDUCATION

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ABSTRACT

The authors describe how hypertext can support learning, especially the creation of cognitive flexibility in product development within an educational context. The concept of cognitive flexibility hypertext is transferred to the special requirements of the regarded domain. It considers the content itself as well as an appropriate structuring and segmentation of product development contents. Moreover, different kinds of hypertext overviews, which provide access to relevant information, are introduced. In this connection a suggestion for product development content is made.
To support cognitive flexibility the reader should be able to access the same content at different times, arranged in different new contexts, for different purposes und from different perspectives. The cognitive flexibility theory assumes that the development of basic principles of case selection and analysis can reduce the time needed for knowledge transfer from documents and maybe even the number of required cases or examples. In this regard, the paper offers several examples of product development content. It is shown that nonlinear, net-like hypertexts play a decisive role.
The approach is strongly case-based. For this reason, different examples of the development process take centre stage. Complex real-world examples have to be analysed and represented along many different, partially overlapping dimensions. An analysis of cases using development methodology steps seems to be useful.

Keywords: cognitive flexibility, instructional material, hypertext, expertise

1 INTRODUCTION

As product development is an integrating function it has to integrate very different content from a broad spectrum of knowledge domains [1]. For this reason, product development is a very complex knowledge domain. It requires a large amount of factual and especially procedural knowledge. Factual knowledge arises directly from the state of technology. It can be verbalised and as a result directly learned from instructional material. In contrast, procedural knowledge is primarily acquired by hands-on learning. It can be verbalised just to a certain degree. Accordingly, it is hardly possible to develop these knowledge structures solely on the basis of instructional documents. Experience plays a decisive role. In the context of practical application, factual and procedural knowledge interact and complement one another [2].
To solve product development tasks a large body of profound knowledge is necessary. This especially means factual and procedural knowledge. Regarding a specific development process, it cannot be assumed that the developer can recall all necessary information without any difficulty. Knowledge could be out-dated, lacking or inaccessible.
Product development tasks are [3]:

- *extensive:* They contain a great variety of different elements and interfaces.
- *networked:* Within a complex system a combination of different elements perform a single or even several product functions.
- *non-transparent*: partial solutions, sub-goals and their requirements are often not obvious.
- *dynamic:* As development tasks are usually part of an extensive project or (social) system, requirements can hardly be derived definitely. Over time, these requirements change several times and have an impact on various aspects.

- *characterised by different goals:* These goals and derived requirements can be inconsistent with each other.
- *time-critical:* Tasks have to be solved over a short period of time.
- *manifold:* As there is not just one single optimal solution, the task can be solved using different approaches, e.g. various combinations of very different methods, tools or even methodologies.

It is quite obvious that this kind of task requires complex knowledge from very different domains. The developer has to choose the appropriate work steps best suited to the current problem. In addition, he has to assign appropriate knowledge elements to these work steps. His operations are finally caused by this procedure. In this connexion, he has to recognise the essential facts, the probability of success and the priority of the most important procedures. Besides this, he has to control the process and the level of sophistication [2].

The complexity and ill-structuredness of a knowledge domain is a major challenge in the transfer and acquisition of “active” knowledge. The learner has to develop complex knowledge structures that contain an extensive “core-knowledge”, “integrating knowledge” (not directly domain-specific, but integrated) and “contact knowledge” (basic knowledge about other domains) [2]. The learned content has to be represented in such a way that it can be flexibly controlled and transferred to new unknown situations. A knowledge representation developed solely from memorising the content is not adequate for problem-solving. This kind of representation contains “inert” knowledge that cannot adequately support the learner. Efficient and effective instructional material has to consider these requirements.

These so-called ill-structured knowledge domains (ISD) are characterised by the following aspects [4]:

- absence of rules or principles of sufficient generality to cover most of the cases
- hierarchical relations or dominance and subsumptions are inverted from case to case
- prototypes often tend to be misleading
- same features assume different patterns of significance when placed in different contexts
- explosion of higher order interactions among many relevant features introduces aspects of case novelty

In contrast, well-structured knowledge domains (WSD) represent much more regular contents. Learning theories dealing with well-structured domains are usually inappropriate for ill-structured domains, because of their inability to establish a basis for knowledge transfer. Such a knowledge base has to enable the application of pre-existing knowledge to new situations. In this context, knowledge transfer for ill-structured domains is best promoted by knowledge representations with [4]:

- multiple interconnectedness between different aspects of domain knowledge
- multidimensional representation of examples/cases
- allowance for various forms of naturally occurring complexity and irregularity

Learning documents can only meet these requirements to a certain degree. A major part of knowledge acquisition has to be achieved hands-on, i.e. real problem-solving. Within this context, practical experience and training concepts are essential. However, as the support of a flexible knowledge representation is very challenging, instructional material should enhance the learning process as much as possible.

2 STATE OF RESEARCH

2.1 Cognitive Flexibility Theory

Spiro et al. [5] define cognitive flexibility as the “ability to spontaneously restructure one’s knowledge in many ways, in adaptive response to radically changing situational demands.” In complex domains, learners do not usually have the opportunity to retrieve an intact hierarchical learning structure from memory. Instead, the mind combines, recombines and reinvents structural components to meet the requirements of each particular situation.

The cognitive flexibility theory (CFT) states that an oversimplification of knowledge, as is often practiced in education, leads to ‘inert’ knowledge. Even though the learner can verbalise inert knowledge, he is not able to use it in practise. That means that the learner has difficulties in transferring this knowledge to new and unknown situations. Thus, instruction should support a multiple representation of knowledge that leads to cognitive flexibility. Instruction should also help to connect abstract concepts with various cases or examples that stress the net-like nature of knowledge. It has to support the early introduction of domain complexity and encourage knowledge assembly [6]. Regarding instructional material, it is essential that the reader revisits the same material at different times and in re-arranged contexts for different purposes and from different conceptual perspectives. [5].

Recommendations derived from the CFT particularly refer to ill-structured knowledge domains. Important learning goals within an ill-structured and complex domain like product development [1] are the ability to flexibly apply conceptual knowledge to new situations as well as the ability to acquire special concepts for reasoning and inference [5]. Therefore, a deeper understanding of the domain's complexity is essential.

It is, however, important to note that a learner without any specific prior knowledge should not be confronted with the full domain complexity. This would exceed his mental resources and would interfere with knowledge acquisition. Accordingly, full complexity should be primarily presented to the more advanced learner.

In general, instruction covers the fields of introductory learning und advanced learning, and is dependent on the learners' prior knowledge. Introductory learning has similar requirements like learning in well-structured knowledge domains, whereas advanced learning is comparable to learning in ill-structured domains. According to [5], optimal strategies for learning in these two fields are entirely different. Table 1 points out some basic differences.

Table 1. Differences between learning in WSD and ISD

	introductory learning and **well-structured domains**	advanced learning and **ill-structured domains**
Knowledge organisation	compartmentalisation	knowledge interconnectedness
Generalisation	general principles with some wide scope of application	cross-case variability and case-sensitive interaction of principles
Representation	single unifying representational basis	multiple representations

General, universal method descriptions with an accompanying example – as can be found in most learning documents for product development – can hardly satisfy the above requirements for ISD. Effective learning documents must consider the complex and poorly structured contents of product development as well as the reader's process of understanding.

In addition to domain-specific knowledge, cognitive flexibility is a central point in the development of expertise in product development. For experts, it is much easier to interpret a set of given information from different and changing perspectives. Accordingly, experts can generate a broader spectrum of possible solutions than novices. As a result, a very important aim in the design of instructional material should be the support of cognitive flexibility - at least to a certain degree.

2.2 Hypertext concepts

Hypertexts are text fragments that are organised in such a way that they overcome the inherent limitations of traditional printed documents. These limitations refer especially to the "philosophy" of structuring, i.e. the way content fragments are segmented and cross-linked with one another.

Regarding conventional printed text, the author decides about the linearity and hierarchy of the contents. He has to define a meaningful, comprehensible order of content elements and differentiates between superior and inferior, as well as more and less important elements. In this connexion, the content is arranged along one single linear thread (cf. Figure 1). The information is related to each other in such a way that information gaps cannot occur. Different chapters and paragraphs are interrelated by references within the text.

Hypertexts are structured in a multi-linear way. Contents are ordered within a content network. This structure enables the author to present the complexity of contents with all its particular details. The contents within one single node of the network should be self-contained, i.e. they should represent an independent fragment of information. The hierarchy of information is not relevant for the construction of hypertext. It is up to the reader to build his own mental hierarchy.

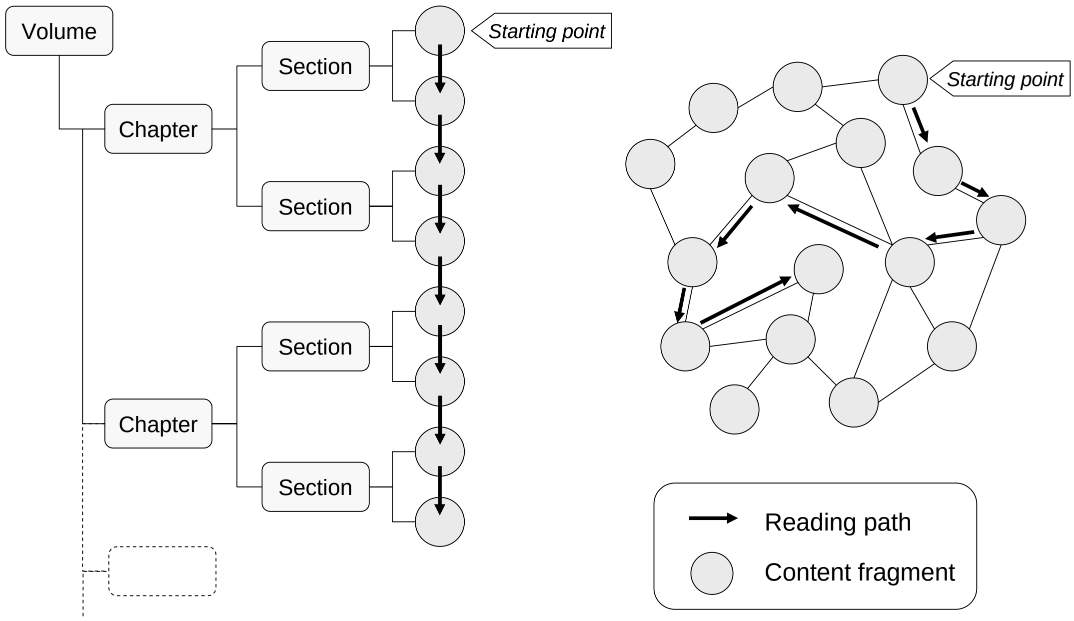

Figure 1. Information structures of texts books and hypertexts

Compared with conventional, printed instructional material, learning with hypertexts is often seen as an ideal medium to communicate complex knowledge. This superiority is usually justified with ‘cognitive plausibility’, even though underlying assumptions are questionable to some extent. Cognitive plausibility refers to the assumption that the net-like structure of hypertext enhances knowledge acquisition because knowledge in the readers’ memory is similarly structured. However, this argumentation is critical as the complex structure of a hypertext cannot be directly transferred to a mental representation. In regard to the reading process, the reader has to find a *linear* way through the net.

The net enables the reader to freely organise a personalised path through the information network. Regarding a printed text the user can passively follow the organization proposed by the author, so hypertext requires active decision-making on the part of the reader. For that reason, it is essential that the reader possesses a mental representation of how the information is organised. As a result, learning with hypertext should be offered primarily to the advanced learner. A novice who does not have a mental representation about the structure would be overloaded: he has to remember the location in the network, make decisions about where to go next and keep track of pages previously visited.

Nevertheless, a well-designed hypertext should enhance the transfer of learning across situations. Its technical characteristics enable the reader to flexibly access the required information.

Jacobson and Spiro [6] confirmed considerable advantages of hypertexts within an experiment. These hypertexts were designed according to the CFT. They were able to prove that hypertexts actually improve the reader's ability to flexibly apply the learned contents and transfer them to new situations. In contrast, they confirmed that linearly organised texts could in fact lead to a better acquisition of factual knowledge. This knowledge, however, was based upon rigid knowledge representations. Inert knowledge was created.

To avoid disorientation, special navigation guides should be integrated in the hypertext concept. Otherwise, the lost-in-hyperspace phenomenon could occur. Navigation guides provide structural information about the contents and can be subdivided especially into textual and graphical overviews.

Textual overviews, like indices, tables of contents and registers are not just restricted to hypertexts, but can also be used within printed documents. Graphical overviews can be subdivided into graphical content overviews and browsers on the one hand, and global/local overviews on the other. The following table gives a short overview of some important orientation guides.

Table 2. Orientation guides for hypertext

Type	Subtypes (examples)	Support for the reader	Recommendation
Textual index	Alphabetical index	Provide information about contents	For well-structured domains or experienced readers within complex domains
	Hierarchical index	Provide information about contents and (partly on) content structure	
Table of contents	Local Table	Provide information on content and hierarchical content structure	For small and well-structured content domains
	Global Table		
Graphical overview	Overview with structural links	Provides information contents, hierarchical structure and content relations	For complex and ill-structured contents without hierarchy
	Overview with referential links		
	Global overviews		
	Local overviews		

3 DEFICITS & RESEARCH QUESTION

The cognitive flexibility theory offers the opportunity to design instructional material in such a way that inert knowledge representations should be prevented – at least to a certain degree. As the theory provides only general explanations for ill-structured knowledge domains, product development has to be related to the underlying assumptions. Today there are no special recommendations on how to enhance flexibility in the design of instructional material. Cognitive flexibility hypertext approaches mainly deal with psychology or economy.

It is quite obvious that conventional printed documents are not the ideal medium to communicate cognitive flexibility. Free navigation to different content can normally not be provided by a book, because of its linear content structure. For that reason, the following concept is based on a hypertext system, which offers the opportunity to flexibly implement different access concepts.

To develop a hypertext concept for method descriptions, the complex and ill-structured nature of product development has to be pointed out. Moreover, the concept of cognitive flexibility has to be transferred to the domain. As there are no suitable recommendations on how to design cognitive flexibility hypertexts, the central elements - derived from the theory - have to be adapted. That means especially the concept of ‘cases’, which plays a central role in cognitive flexibility hypertexts. For that reason, product development cases representing method descriptions have to be defined and implemented in the hypertext. Their relationships to other concepts within the domain must also be reflected.

4 CHARACTERISTICS OF THE IMPLEMENTED HYPERTEXT CONCEPT

According to the criteria of the previous paragraphs, product development can be considered as an ill-structured knowledge domain. The following examples amongst others underline this assumption:

- There are no general rules or principles that guarantee optimal solutions for a development task.
- The impact of a single method on finding the solution varies a lot.
- General statements and recommendations about the procedure can be misleading and must be adapted to the specific situation.
- Within a development process, the same initial conditions can lead to solutions that meet the requirements to the same extent but are based on very different concepts.
- A set of certain requirements within a development process can result in different procedures and accordingly in very different solutions.

The complexity mainly results from the multifaceted characteristics of the development task and from the great variety of different knowledge domains that have to be integrated. In product development, conventional documents (text books, lecture notes, etc.) often show deficits similar to the shortcomings of approaches to knowledge representation. Learning with these kinds of documents can only support the learning process in regard to cognitive flexibility to a certain degree. Deficits of the regarded documents and the derived knowledge representation refer to the following points [5]:

- *Information is pre-packaged*, as a result the learner has little opportunity to adapt it to diverse contexts of knowledge use.
- *Knowledge is compartmentalised*, but knowledge and therefore content need to be interconnected.
- *Complexities are artificially neatened*, but there should be an emphasis on the domain's complexity and difficulties.
- *Too much regularity is assumed*, but irregularities are a central point.

From this it follows that the learner should be faced with the complexity of relationships and procedural methods as early as possible. It is, however, critical to confront the reader with full complexity from the very beginning. This could lead to cognitive overload and would have negative consequences on the learners' motivation and acceptance of the document. Accordingly, the readers have to be provided with different documents that consider their individual level of prior knowledge.
To present the domain's complexity in a realistic way, the reader has to be provided with information about very different fields of method application. Moreover, a broad range of different initial situations, solutions and problem procedures has to be introduced considering different alternative methods and methodologies. For the more advanced reader, isolated, prototypical examples of method application should be eliminated as much as possible. Rather, the learner must be provided with very different examples of problem-solving, in order to support the construction of a flexible multi-perspective representation. It is quite obvious that knowledge must be flexibly controlled, when it cannot be routinised, mechanised and automated.
Within other knowledge domains, hypertext concepts contain different structural components that are related to one another. A concept to support cognitive flexibility has to contain, e.g., the following elements [10]:

1. **Comprehensive Cases** are a central point within the concept of cognitive flexibility hypertexts. These cases should not cover prototypical situations but many wide-ranging cases, which illustrate the multidimensional nature of real life experiences.
2. **Themes** are ideas or concepts expressed by subject experts and should enable the reader to understand the complex scenarios. According to the CFT, hypertexts require the use of multiple themes with the widest possible scope.
3. **Mini-Cases** are disassembled fragments of a case and represent text selections and figures from complete cases or scenarios. Mini-cases are short statements, which enable the reader to recognise a major theme and its relations to the case.
4. **Perspectives** are conceptual and semantic elements within a mini-case. Perspectives can be realised by hyperlinks, hot words and phrases, etc. They link to relevant points in other perspectives and lead to a multiple representation of important ideas und concepts.

To place emphasis on the domain's complexity, the hypertext should contain entire development projects and present them to the reader. According to the above classification, these projects correspond to the content type of *comprehensive cases*. For that reason, development projects are a central element of cognitive flexibility hypertexts presented in this paper. In this context, a wide range of different initial situations for development projects has to be integrated. These result in very different requirements, and accordingly, in various solutions. In doing so, the multi-dimensional nature of product development is presented at least to a certain degree. The description has to consider real-life conditions, including potential and real problems, difficulties, barriers and iterations. Content has to be presented according to the comprehension case, i.e. the development project(s).
In addition, theoretical background knowledge reflecting prototypical situations has to be presented along the way. In this context, it is important to consider all potential options for action, including a

statement about which option is most suitable for the described situation and why. These content items correspond to the content type of *themes* and should consider the widest possible scope. Following the concept of comprehension cases, they have to be assigned to the corresponding example within the development process. In regard to this, potential problems of method application and alternative actions have to be pointed out. If necessary, these have to be described in detail. In doing so, the reader has the opportunity to develop a holistic representation of a task's complexity.
The concept of *mini-cases* can be transferred to product development by describing single method applications in detail. The topic should be extracted from the comprehension case. The relationship to the superior development process, however, has to be pointed out. Regarding the mini-case, a self-contained content fragment should be presented to the reader. If all mini-cases are described consistently, the entire development project can be assembled from mini-cases. Even though mini-cases are self-contained, the relevance for the whole development process has to be underlined (cf. Figure 2). Regarding a single method description, all work steps have to be presented step by step according to the comprehension case. In doing so, the abstract description can be transferred to the specific project with low cognitive effort.

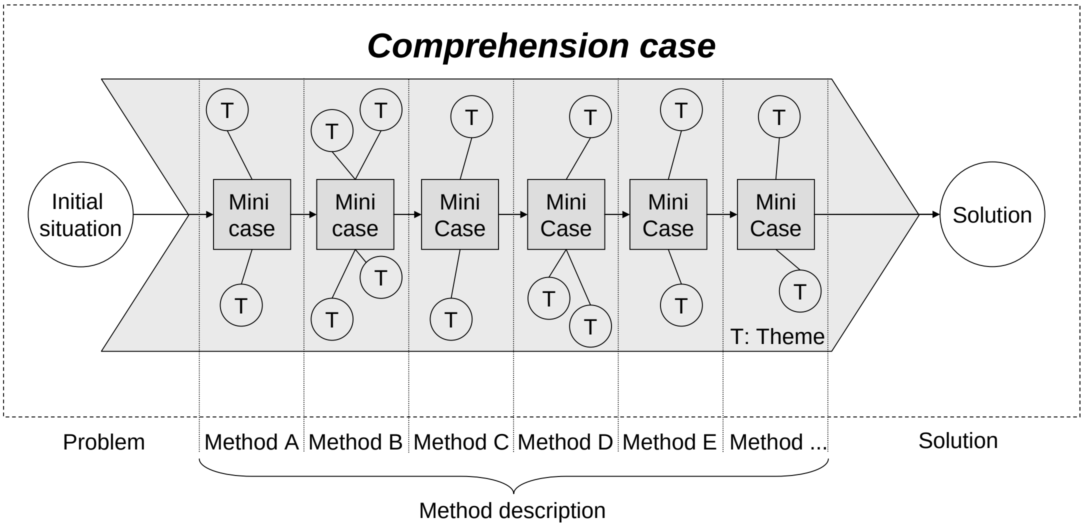

Figure 2. Method descriptions with a comprehensive case

The isolated presentation of a single comprehension case could, however, create prototypical knowledge representations. The transfer of knowledge to new situations would not be supported very well. As the learner has to acquire knowledge which can be flexibly controlled and transferred, a broad spectrum of development projects (= comprehension cases) has to be integrated. Thus, the reader has the opportunity to switch between various cases considering very different situations and requirements. In this context, products and applications from various industries have to be provided. These have to be described in such a way that the reader obtains information about potential advantages, disadvantages, problems and risks of method application. Even examples of an ineffective method application should be presented with caution, to cover as many real-world situations as possible. The reader should get a realistic overview of the methods' potential benefits.
Figure 3 shows one possible path a reader can take through a content network of a method description that is designed according to the above requirements. This concept is already implemented in a hypertext system providing content about the development of function structure for students. In this hypertext, the student has the opportunity to study all work steps from function analysis to function variation while switching between different comprehension cases.
The figure shows that free navigation through the content has to be realised by a hypertext concept. A static medium such as printed documents cannot offer this kind of flexible access, at least with acceptable efforts for the reader, although some navigation elements (glossaries, cross-links) can be transferred to a certain degree, e.g. by references. But regarding print documents, this kind of flexible access is a rather theoretical option, as it implies remarkable cognitive efforts on the part of the reader. In this context, hypertext can be seen as an ideal medium for the described content structure.

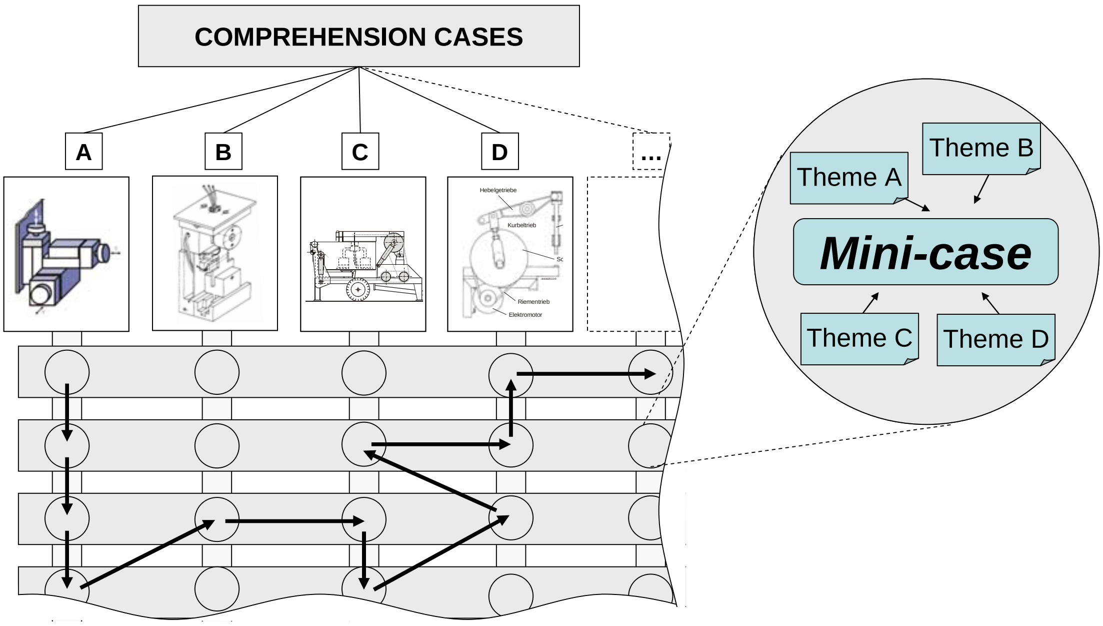

Figure 3. Fragment of a content network for method descriptions

As learners on different levels of expertise need different content structures, the freedom of navigation has to be adapted to the readers' requirements. More precisely, it must be increased step by step according to the readers' experience.
In the regarded context, a layman can access just one single development project, until he has acquired a basic comprehension. With increasing knowledge, the reader's freedom is expanded to parallel comprehension cases until he has free access to all content within every case. At this point, cognitive flexibility is best supported.
The implemented hypertext system also contains some iteration steps, reflecting loops in real-world development tasks. The reader should not get the impression that product development follows a strict sequence without any loops. In fact, iterations are a central characteristic of development processes. For that reason, content considering this aspect has to be integrated in the hypertext structure (cf. Figure 4). In addition, the hypertext has to provide information about the changed conditions and reasons for the presented iteration as well as the changed output of method application.

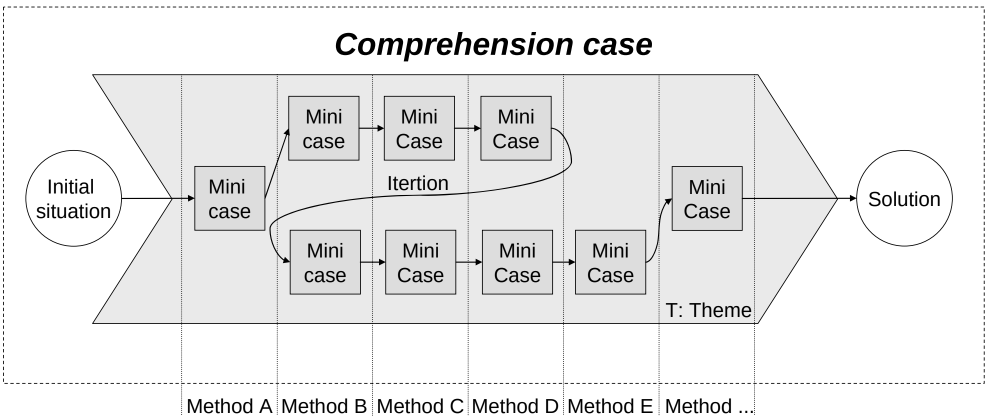

Figure 4. Iteration within the development process

It is quite obvious that it is almost impossible to integrate all potential iterations in the content structure, as they are countless. An extended structure should simply underline the increasing complexity and irregularity of the case. Besides, the reader has to learn that the presented solutions are just one single possible result of the process. Accordingly, a complete integration is neither necessary nor important. Besides, it would mean a substantial effort for the author(s).

To support navigation within the hypertext, graphical overviews referring to product development methodology are integrated in the hypertext system. Graphical overviews are superior to textual overviews as they enhance comprehension more effectively [7]. In this context, it is important to note that navigation guides must be designed especially for those users who have access to a broader content base. For novices who are restricted to one single comprehension case, the “lost-in-hyperspace” phenomenon is unlikely to occur. For them, very simple guides can be provided.
Finally, the following table shows the basic principles of the CFT in regard to the design of hypertext. The right column shows examples from the implemented learning hypertext, concerning the development of function structures. The underlying concept is based upon three stages, reflecting the learning progress, i.e. the novice stage, the intermediate stage and advanced stage (loosely based on [6]).

Table 3. Basic principles in the implemented hypertext

Theoretical fundamentals	**Hypertext features**	**Example *function structure***
Novice stage		
Introduce a basic domain concept to prevent cognitive overload	Access solely to single isolated content fragments	Access on just one single development case
Provide basic orientation in the domain	Rough graphical overview on basic concepts	Graphical overview on work steps for the development of function structures
		Graphical overview on basic terms and their relation (e.g. function analysis, variation, synthesis)
Intermediate stage		
Create multiple conceptual representations of knowledge	Links to multiple cases and multiple dimensions of a complex concept	Links to similar development cases
Link and tailor abstract concepts to different case examples	Theme list, theme commentaries and extended graphical that accompany case presentations	Selected information about related topics and methods
		Extension of an (adaptive) graphical overview on terms and proceedings related to function structure
Introduce domain complexity successively	Mini-case organizational structure	Links between Mini-cases of similar development cases
Advanced stage		
Stress the interrelated and web-like nature of knowledge	Full access to the whole content network, no mandatory guidance, perspectives	Perspectives to all development cases
		Perspectives to other methods and terms (functional costs, value analysis, etc.)

5 CONCLUSION OUTLOOK

Hypertexts can be an important instrument for knowledge transfer and for the development of cognitive flexibility. The case-based concept of cognitive flexibility hypertexts is very suitable to product development, as cases are a central element of the domain. However, instructional material can be seen just as a small building block within a comprehensive learning and training concept. It can support learning but it cannot substitute exercises of method application.

Following the cognitive flexibility theory, method descriptions must be integrated in development cases and examples. To provide support for the development of multiple representations of method application, very different examples are successively or even simultaneously presented within the implemented hypertext system. Supporting the acquisition of multiple representations, the more knowledgeable reader is able to switch between these examples without any restrictions.

By these means, the flexible applicability of methods is pointed out. Moreover, this kind of method presentation makes clear that methods do not have a fixed character, but should be applied flexibly to the specific situation. According to the CFT, generalised method descriptions with a single isolated example are hardly appropriate as effective instructional material.

A broader cross-linking of content associated with a minimised structure can support the development of cognitive flexibility. However, the reader's individual level of expertise has to be considered – at least at the initial presentation. A novice would sustain a cognitive overload due to his limited cognitive resources. The cross-linking should be extended gradually in accordance with the level of prior knowledge. Individual adaptive topic maps could be a possibility to provide a user-specific overview of the content. At the same time, they could restrict free navigation through the content depending on one's level of expertise.

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