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Theoretical Concepts for Using Multimedia in Sience Education

GIRWIDZ, R., *RUBITZKO, T., *SCHAAL, S., **BOGNER, F. X.,
**University of Education, Ludwigsburg, Germany, **University of Bayreuth, Bayreuth, Germany*

ABSTRACT *Multicoding (using various kinds of representation), multimodality (addressing several senses), and interactivity are special features of multimedia. We derived several guidelines on the basis of psychological findings in order to apply multimedia, specifically designed to assist effective learning in complex fields of knowledge. We focussed on promoting cognitive flexibility, building adequate mental models, implementing "situated learning," structuring knowledge and linking fields of knowledge, as well as adjusting cognitive load. In this contribution, we present an overview of theoretical considerations and illustrate possible implementations. The aim was to delineate guidelines for a theory-guided development of multimedia applications.*

KEY WORDS: *Multimedia, ICT, science education, situated learning.*

Introduction

Modern media offer innovative and specific information and communication opportunities that address multimodality (*i.e.*, the possibility to address several senses), multicoding of information (*i.e.*, offering different presentations and code systems), and interactivity with a learner/user. When focussing on learning processes, it should be clear that these features characterize a rather superficial structure of communication and interaction, and further aspects of learning have to be considered. For example, multicoding might be helpful in assisting learning by combining the potential of different code systems. However, combining representations may increase the density of information and generate cognitive overload.

Therefore, further aspects of learning should be considered that extend beyond the superficial perceptual structure. This paper derives some theoretically well-founded ideas to cope with several requirements from the psychology of learning, as it is shown in the overview of Figure 1.

Multimedia in Science Learning

The Superficial Structure of Information and Interaction:
Multimodality Multicoding Interactivity

Deeper Structure of Learning:
Cognitive Flexibility / Situated Learning
Cognitive Load / Knowledge Structure
Mental Models

Figure 1. Theoretical Concepts for Using Multimedia in Science Education

In the following, we briefly outline some underlying theories and subsequently describe some specific examples with the intent to bridge the gap between theory and practice. The intention is to show how multimedia applications can be designed according to relevant theoretical guidelines. A subsequent paper will suggest a specific 6-lesson unit based on the described theoretical guidelines (Girwidz, Rubitzko, Schaal, & Bogner, present issue).

Multimodality, Multicoding, and Interactivity

Firstly, we consider the superficially noticeable aspects of interaction with multimedia. According to Weidenmann (2002), multimodality, multicoding, and interactivity describe special features of information and communication structures, offering new ways for teaching and learning. Multimedia applications normally address aural and visual senses. Interactivity is expected to have motivational effects by creating a new sense of responsibility for a learning process and by permitting learners to play an active role.

Multimodality (Sounds and Pictures)

A multimedia application presenting audio and visual information activates different sensory systems and provides a more realistic and authentic approach. Mayer (1997) described the combined presentation of verbal and visual information as specifically helpful for inexperienced learners. Mayer and Moreno (1998) outlined a split-attention-effect and better learning results when verbal and visual aspects are combined, compared to a written text alone. The authors assumed the importance of two separate channels for processing visual and auditory information in working memory. The combination of verbal and written components, therefore, may lead to a better processing in limited working memory (Moreno & Mayer, 1999).

Multicoding

Weidenmann (2002) highlighted the importance of different coding systems when using multimedia to promote learning. Any processing of information is based on code-specific expressions, especially in the early stages of a learning process. Additionally, physiological studies provided evidence that specific cerebral cortex areas are responsible for processing textual and visual information (Springer & Deutsch, 1998). Different codes offer different ways to communicate information, but they require specific skills. Schnotz and Bannert (2003) distinguished textual and pictorial representations, and stated that even different kinds of visualization engage different knowledge structures that are useful for specific applications. However, illustrations embedded in texts do not inevitably result in positive effects. Only less gifted learners seem to profit generally from pictures in text. Gifted students seem to be able to develop an adequate mental model without pictorial presentations (see Schnotz & Bannert, 2003; Mayer, 1997). Visualizations are useful if they present facts and concepts in task specific ways. Otherwise, they interfere with other concepts and might even cause difficulties (Schnotz & Bannert, 2003). Therefore, a task specific and appropriate form of presentation plays an important role in learning.

Interactivity

Learning theories more and more emphasize active learning and self-pacing in learning situations. Herewith, adequate and individual feedback is considered as a fundamental prerequisite. Computers offer remarkable advantages for interactive learning (Steppi, 1989). Real interactivity requires that (i) learners can be creative, and may choose and modify contents by themselves; (ii) the program adapts and dynamically reacts to learners' actions; (iii) learners gain control over the processes of learning; and (iv) assistance or guidance is given on demand by the multimedia system. Interaction and communication might become even more attractive by the use of light pens, voice recognition, data gloves, and/or eye cameras. However, users have to be familiar with the information technologies and be able to use them appropriately. New skills are required to cope with the new possibilities, and to organize and structure multiple sources of information.

In summary, multimedia systems offer new possibilities for presenting knowledge and a better accessibility to data. They can combine information, make it available in flexible and interactive ways, and help to realize the spatial and temporal contiguity principle, meaning that corresponding texts and pictures are closely positioned together and presented simultaneously (rather than successively).

Theoretical Guidelines and Concepts

These features of multimedia characterize superficial structures of a learning environment. To make them effective for learning, they should be part of a more detailed conceptualization. Mayer (1997, 2001) presented a theory and empirically well-founded guidelines for multimedia learning based on three theoretical assumptions. First, the human information processing system is based on two channels for auditory and visual input, meaning that verbal and pictorial information is processed separately. Second, each channel has a limited capacity. Third, learning requires active processing and happens when attention leads to the selection and organization of perceived information, so that it can be integrated coherently in an existing knowledge structure. All these processes are sensitive and can easily be upset by cognitive overload. Mayer and his group present a well-investigated catalogue of effects that should be considered when designing multimedia applications for learning. Among them are:

(i) Multimedia effect: Learners perform better when information is presented in words and pictures than in words alone.

(ii) Modality effect: Better transfer is expected when animations are offered together with narration rather than with written text.

(iii) Spatial contiguity effect: Learners perform better when text is placed near rather than far from corresponding pictures.

(iv) Temporal contiguity effect: It is better to present animations and corresponding narration simultaneously rather than successively.

(v) Coherence effect: Irrelevant words, pictures, and sounds should be excluded.

(vi) Redundancy effect: There is better transfer from animation and narration than from animation, narration, and on-screen text.

(vii) Signaling effect: Better transfer is achieved when narration is signaled rather than non-signaled.

(See Mayer, 2002, also for the pre-training effect and personalization principle.)

These effects were investigated using short multimedia applications dealing with cause-and-effect-chains and explaining how things work, *e. g.*, how a bicycle pump or car brakes work, or how lightning storms develop. When using multimedia for more complex contents and for teaching units comprising more than one lesson, further theories and guidelines become interesting to assist and manage complex systems and interrelations. Due to space limitations, only the basic ideas can be sketched here. References to the literature are presented for those requiring more details. Specific examples are presented in every segment to illustrate how to apply theory and how to bridge the gap between theory and practice.

Looking at complex fields of knowledge acquisition, it is intended to (i) foster a flexible use of various kinds of knowledge representations, (ii) help to develop adequate mental models for science phenomena, (iii) assist in constructing a well organized knowledge structure to guarantee access to knowledge that is needed for problem solving and applications, (iv) use rich contexts and arrange situated learning and anchored instruction, in order to avoid "inert knowledge," and, last but not least, (v) use the special benefits of multimedia, *i.e.,* multimodality, multicoding, and interactivity, without producing cognitive overload.

Fostering Cognitive Flexibility

"Cognitive flexibility" includes the ability to restructure acquired knowledge according to the demands of a given situation (Spiro & Jehng, 1990). Thus, a knowledge ensemble can be constructed tailored to the needs of a problem-solving situation, or to support learning and linking of new concepts (Spiro, Feltovich, Jacobson, & Coulson, 1992). Cognitive flexibility helps to apply knowledge under various conditions in an effective way.

a) Cognitive Flexibility and Multiple Representation

To foster cognitive flexibility, knowledge should generally be consolidated from different conceptual perspectives. Knowledge should be structured and taught in different forms to be functional in multiple situations. One assumption of the cognitive flexibility theory is that specific learning environments are needed. Facts should be presented and learned in many different ways, and knowledge should be integrated in a variety of scenarios (Spiro, Coulson, Feltovich, & Anderson, 1988; Spiro et al., 1992). This is particularly important for ill-structured knowledge domains with high across-case irregularities and conceptual complexities. Kozma (2003), for instance, described a difference between experts and students (novices) regarding the use of multiple representations. While experts use them with purpose, novice students may face difficulties in connecting multiple representations adequately. Their observations and arguments often limit themselves to superficial features. Novices also tend to concentrate on a single description, while experts use various representations and seem to alternate easily from one to another. In general, mental multi-coding improves access to knowledge and problem-solving techniques.

The application in Figure 2 shows a camera in a realistic arrangement (photography) combined with an abstract drawing. Manipulations of a realistic camera, simultaneously cause modifications on an abstract drawing. For example, changing the aperture modifies the bundle of light entering the camera. Thus, learners are assisted to build connections between different representations.

In general, linking textual, mathematical, and pictorial representations may facilitate a proper handling of problems.

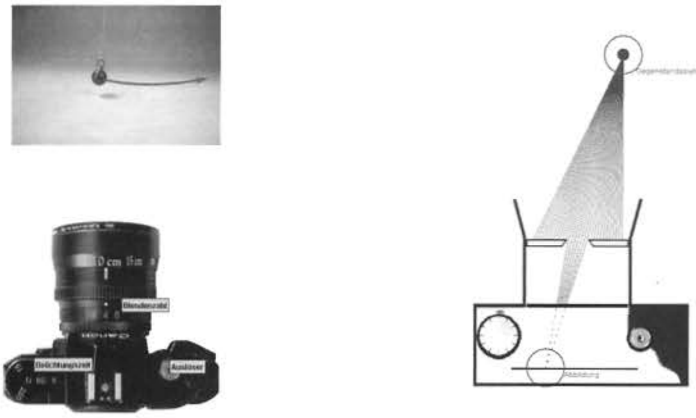

Figure 2. A Virtual Camera in Two Representations.

b) Restructuring

Mastering different symbol systems is one area of competence, the other is coping with various descriptions in a single system. For example, identical wiring diagrams, as those presented in Figure 3, can be drawn so differently that novices may not recognize these circuitries as identical. Computer animations can illustrate equivalence among these circuitries by showing the essential transformations step by step (see also Härtel, 1992).

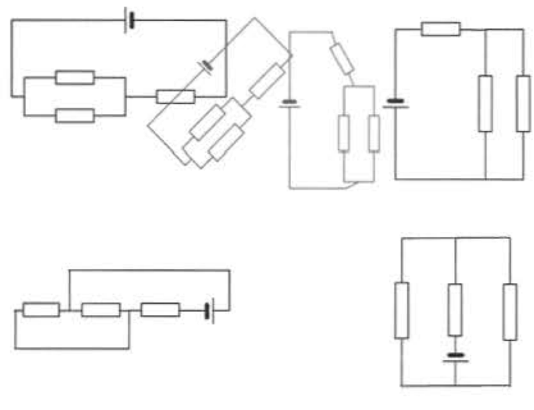

Figure 3. Several Frames of a Computer Animation, Subsequently Transferring One Circuitry into Another (to Show Their Equivalence).

c) Supplantation

The so-called supplantation principle may provide substantial support in relating different operations to each other (Salomon, 1979, 1994). An example is detailed in Figure 4, describing the behaviour of an oscillator both in a representation similar to reality, and by the use of a corresponding y(t)-diagram. The arrow connects the concrete and the abstract representation. As the oscillator is moving up and down, an arrow points to corresponding positions in the graphical description of this process. Thus, the concept of a line graph is illustrated.

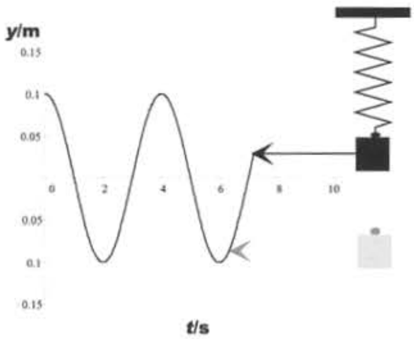

Figure 4. Frame of an Animation: Y(t)-diagram and the Corresponding Scenario.

d) Comparing and Linking Different Representations

More gifted learners can discover interdependencies on their own, when corresponding representations are offered simultaneously. For example, the computer program "Atomos" supports the understanding of sub-atomic structures in physics by describing electron densities within a hydrogen atom (Girwidz, Gößwein, & Steinrück, 2000), as indicated in Figure 5. Different kinds of diagrams

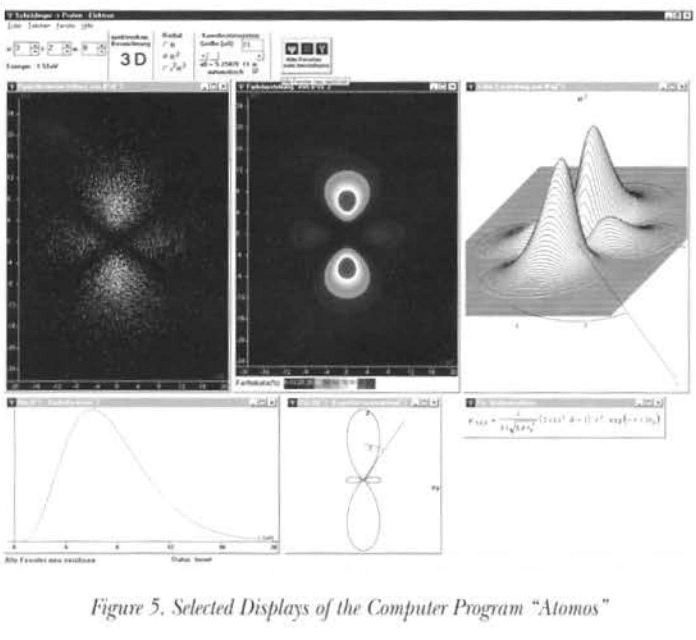

Figure 5. Selected Displays of the Computer Program "Atomos"

and figures are put together. All of them describe the same issue – the probability to find the electron at a certain position. Density of dots, intensity of colours or relief contours lead to an intuitive understanding of high and low values.

e) Linking Knowledge by Using Hypermedia Systems

Spiro *et al.* (1992) described "ill-structured domains" as knowledge domains with a complex structure that may mislead novices in particular. In order to connect multiple facts with various aspects in such a domain, a whole field of knowledge needs to be worked through. Multimedia can offer support: A nonlinear medium like hypertext might be very well suited for the kinds of 'landscape criss-crossings' recommended by Cognitive Flexibility Theory (Spiro *et al.*, 1992). In hypermedia systems, relationships are represented by links interconnecting information nodes. These nodes are compositions of textual or pictorial representations, audio-visual information in videos, animations, or interactive simulations. The information nodes can be organized sequentially, hierarchically, or arbitrarily. By linking multiple kinds of information, hypermedia systems can promote a flexible access on knowledge.

Construction of Adequate Mental Models

The term "mental models" points to analogous cognitive representations of complex interdependencies within a knowledge domain. A classical example is the functioning of a steam engine or an electric buzzer (De Kleer & Brown 1983) that is exemplified in Figure 6. The design of multimedia applications can be based on the underlying theories, particularly when external pictorial representations are employed.

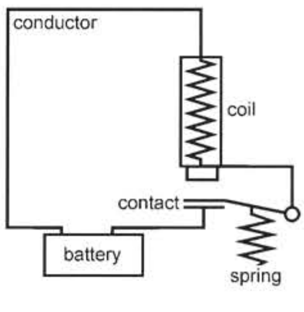

Figure 6. Electric Buzzer (from de Kleer & Brown, 1983).

For research in teaching and learning, mental models offer an attractive theoretical background. They are increasingly used for explanations, but, unfortunately the term is not used consistently (Ballstaedt, 1997). This paper follows the initial definition of Johnson-Laird (1980), Forbus and Gentner (1986), Seel (1986), and Weidenmann (1991). Mental models are analogous, pictorial representations enabling the brain to simulate complex systems and to imagine how they might work under different settings. Typical examples within such a context are imagining astronomic processes, atmospheric circulation, or plant photosynthesis. Mental models follow the assumption that human beings construct cognitive models of reality, reflecting aspects that are important for an individual. They give a reference frame for understanding new issues and provide a base for subsequent planning (Dutke, 1994).

Superficial configurations and deeper structures should be distinguished. Furthermore, Einsiedler (1996), as well as Schnotz, Bannert, and Seufert (2002), discriminated the medial representation and its corresponding sensory perception on the one hand, from the fundamental subject structure, on the other. Hence, multimedia merely can assist the construction of mental models and can only give hints in external representations, while mental models are constructed in the brain of an individual learner. Seel (1986) added two further aspects to be considered: the compatibility of external representation to the internal mental representation, and its specific fit to a particular topic. Nevertheless, due to its specific features, multimedia provide the best basis for presenting information and supporting adequate mental models (Issing & Klimsa, 2002).

Multimedia and Mental Models

Multimedia may combine several types of presentation and thus avoid overemphasising superficial aspects of a specific representation. Figure 7 combines a real setting (photography) with a graphical representation. The photography is (gradually) substituted by an abstract symbol set within a dynamic computer visualization, illustrating the underlying process for the development of clouds within a temperature inversion setting. Different shades of grey in the right picture indicate the temperatures involved, and arrows show the flow of air (Figure 7). Such an analogous external representation may help in constructing an adequate mental model.

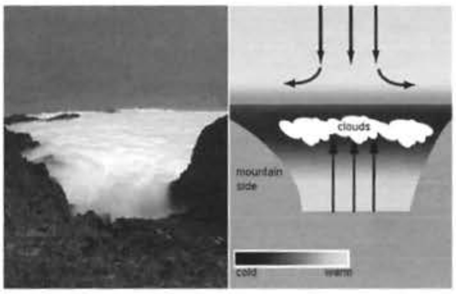

Figure 7. Different Kinds of Visualization Explaining the Development of Clouds in a Valley.

Weidenmann (1991) specified different types of support for the construction of mental models when using illustrations: (i) Activation: Pictures can activate an already existing mental model and establish starting points. (ii) Construction: Illustrations can show how single well-known components are integrated within a superior structure, and hence assist in structuring and unifying knowledge. (iii) Focus: Pictures can emphasize special aspects of an existing mental model and may adjust or elaborate these aspects. (iv) Substitution: Visual representations can illustrate complex and dynamic aspects to show the interplay of settings in models. (Pictures can also be lined up to yield animations and show time dependent aspects.)

Besides pictures or animations, interactive simulations may clarify important correlations and relationships and assist in the construction of adequate mental models.

Situated Learning

Theories of situated learning consider learning as dependent on activity, context and cultural environment (Lave 1988; Lave & Wenger, 1990). Consequently, (i) knowledge has to be presented in authentic contexts, under circumstances and in applications where this knowledge normally is used, (ii) learning needs social interaction and cooperation.

In the following, we consider the first aspect:

a) Anchored Instruction

Anchored instruction (CTGV, 1993; Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990) implements some theoretical aspects of situated cognition theory. One important intention is to overcome "inert knowledge," knowledge that can be repeated in classroom tests, but cannot help in situations where problems need a solution. Initially, researchers of the GTGV (Cognitire Technology Group of Vanderbilt) focused on the development of interactive videodiscs intended to support and stimulate students (and their teachers) to deal with complex, realistic problems. Those videodiscs provided interesting, realistic "anchors" as kick-offs for teaching and learning. Their narrative character is intended to catch students' interest and motivate them to investigate the problems presented.

The content involved (i.e., facts, concepts, theories and principles) must be meaningful for an individual. Thus, knowledge gain is both a valuable result and simultaneously a tool to cope with relevant questions. Specific "anchors" may link knowledge to applications and offer a framework for integrating knowledge from different domains. Anchoring knowledge to realistic frames is thought to support specific problem-solving strategies (Goldmann, Petrosino, Sherwood, Garrison, Hickey, Bransford, & Pellegrino, 1996).

b) Simulating and Modelling of Problems

A deeper understanding of relevant parameters in realistic scenarios may arise from simulations and programs which allow modelling. An example is the calcula-

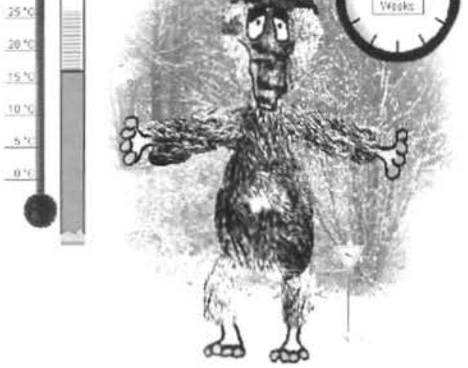

Figure 8: Modelling Different Strategies of a Virtual Mammal to Successfully Survive Winter. Variables, such as, Insulation, Body Size, and Mobility Have to Be Chosen.

tion of energy requirements for a room, where the size, the kinds of walls, windows and insulations can be varied. Similarly, for interdisciplinary learning the energy balance of living beings is an interesting topic. Surviving a winter needs variables, such as insulation, ingestion, and mobility to be taken into account. A specific application is shown in Figure 8 (virtual mammal). Therefore, different habitats or hibernation strategies (such as winter-dormancy) can be varied as well as the body size and the fur's attributes. Learners can test their chosen settings via this simulation and get instant feedback.

Structuring Knowledge

De Jong and Njoo (1992) identified two important parts of learning processes: structuring knowledge and linking it to prior knowledge. Well structured and properly organized knowledge is also important for problem-solving (Reif, 1981). A hierarchical structure improves accessibility and key words can point to relevant details. Van Heuvelen (1991) attached special importance to mediating general principles. Clark (1992) distinguished vertical linkage (*e.g.*, assigning a problem to a general principle) and horizontal linkage (*e.g.*, connecting a problem to similar knowledge structures, such as analogies). Horizontal links are of special interest when transfer is requested. Charts, mind maps, and diagrams may illustrate cognitive connections, help to analyze a knowledge domain, and improve recognition and recall of specific learning matter (Beisser, Jonassen, & Grabowski 1994). Effective knowledge management involves a well-organized structure of knowledge and includes techniques to refine and extend declarative and procedural knowledge.

a) Notations

Mind maps and concept maps are structured displays of key terms, including also text-picture combinations. Concept maps represent a knowledge domain by using nodes (usually specific key words or central statements) and lines to indicate connections. So-called "reference maps" aim to depict knowledge structures and offer an appropriate frame for access to information. Charts in particular accentuate a hierarchical structure and show vertical and horizontal arrangements. Thus, these features provide a useful framework for transforming knowledge into a visual representation, which can easily be communicated. Visualized knowledge structures may assist various instructional aims (Ballstaedt, 1997), for instance, to mediate statements, to memorize knowledge and/or to offer threads for explorations. However, a simple transfer from external to internal representations cannot be assumed (Einsiedler, 1996). Presenting knowledge structures is also insufficient for Jonassen and Wang (1993), who call for active processing and working with them.

b) Charts, Maps, and Computers

Structured network presentations are of special interest in modern multimedia applications. They meet the demands of modern theories of mental representations and at, the same time, suit current programming techniques. Programmed modules contain details, horizontal and vertical connections are covered by "links." Especially hypertext can replicate the semantic structure of a knowledge domain. Nodes represent terms and links indicate logical connections. Hypermedia applications can be seen as a refinement of hypertext, integrating pictures, graphs and animated visuals. They can also expand on demand, to show more detailed structures. An example is shown in Figure 9, categorising different sources of electric energy and illustrating each type by a picture.

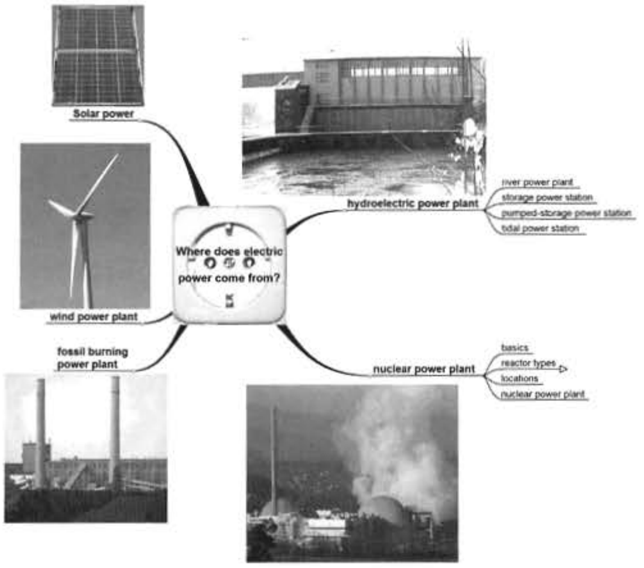

Figure 9: Different Sources of electric Energy. Students May Move to Corresponding Pages by Clicking on the Terms.

Flexibility, adaptability, and networking are special advantages of modern media in supporting the structuring of knowledge. Drawing maps with modern computer programs is very simple. Even beginners can apply them and tailor learning paths specifically to their individual demands and interests (Girwidz & Krahmer, 2002).

c) Advance Organizer

Learning with hypermedia often lacks appropriate scaffolding and a process-oriented guidance. Advance organizers may be realized as a reference map and can assist goal-directed learning. At the beginning of a learning unit, such a framework can also help to understand the overall context. Furthermore, structured maps may avoid the so-called "lost in hyperspace" syndrome.

Considering Cognitive Load

a) Limitation of Working Memory

Baddeley (1992) described three subcomponents of working memory: (i) The central executive, which controls attention and integrates information from two subordinated systems, (ii) the visual-spatial sketch pad which processes images and (iii) the phonological loop, which deals with acoustic information. The capacity of individual working memory seems to be strictly limited to less than seven so-called chunks (grouped and organized entities of knowledge learned in the past). However, the information quantity grouped within a particular chunk seems to be nearly unlimited (Miller, 1956; Baddeley, 1990).

b) Determinants for Cognitive Load

"Cognitive load theory" (Sweller, 1994) focuses on the limitations of working memory as an important factor for learning (Chandler & Sweller, 1991). Under adverse circumstances, perceiving and processing information may require even more cognitive capacities than understanding the material itself. For example, studying equations with unfamiliar notations causes a heavy cognitive load due to unknown expressions, which need interpreting (Leung, Low, & Sweller, 1997). Any confrontation with an unfamiliar code system is very likely to produce a heavy strain on mental resources (Seel & Winn, 1997).

Additionally, interaction between learners and the operation of a computer program contribute to cognitive load. Thus, cooperative discovery learning with interactive animations, for example, may produce high cognitive load, because of the need for simultaneously coordinating interactions with peers (Schnotz, Böckheler, & Grzondziel, 1999). Also subject matter can overstrain cognitive resources if too many elements have to be processed in working memory. In order to reduce cognitive load, singular elements should be combined to form meaningful units before further working. Marcus, Cooper, and Sweller (1996) put this approach into concrete terms and explained that, for example, diagrams can provide such schemas for functional dependencies in mathematics and science.

The use of different sensory modalities normally reduces cognitive load (Tindall-Ford, Chandler, & Sweller, 1997), unless the presentation itself causes a load, e.g., for net-working auditory and visual information (Jeung, Chandler, & Sweller, 1997). Supplementary visual information in texts may produce overload by absorbing too many cognitive resources of the visual information processing channel, whereas additional acoustic information in computer based environments may reduce cognitive load (Kalyuga, Chandler, & Sweller, 1998). The use of colours for guiding purposes and for indicating details in pictures may be helpful. Additional written text, however, may increase cognitive load, if learners have to switch between processing pictorial and textual information (Kalyuga, Chandler, & Sweller, 1999).

Figure 10 illustrates a bird's strategy in cold environments to minimize the energy loss in their (un-insulated) legs. The animation is supplemented by appropriate verbal explanations. Furthermore, details that are not necessary for explanations are faded out. The temperature is displayed next to the veins in order to avoid a split-attention-effect. Appropriate colours indicate cold and warm areas and provide a visual impression of temperature distribution.

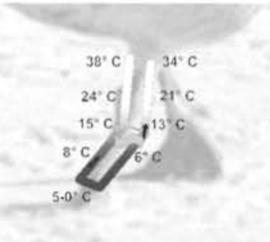

Figure 10: Reduction of Cognitive Load by Narration and Colour Coding.

"Cognitive load" is additionally influenced by a learner's expertise. So, for novices any new information of a specific knowledge domain should be pre-organized before implementation (Tuovinen & Sweller, 1999). However, if, for example, for experts a diagram is clear without textual explanation, redundant information in additional text would unnecessarily increase their cognitive load (Kalyuga *et al.*, 1998).

Self-directed learning may also cause cognitive overload, if learners have to decide which information is needed next, or where to find required information or how relevant specific information can be. Additionally, technical problems or problems with the user interface may appear.

c) Control Information Flow in Order to Adapt Cognitive Load

Sweller (2002, 1994) suggested a classification of learning materials by taking into account whether within a working memory information may be processed step by step or simultaneously. Furthermove, cognitive load strongly depends on content aspects. Therefore, we can only suggest few general principles to control the information flow and to adjust cognitive load. Three approaches are: (i) Allow users to control the progress of work and admit adaptation to their individual requirements; (ii) arrange information according to the principle of temporal and local contiguity, meaning that information should be presented when and where it is needed. For instance, text and pictures belonging together should not be separated (Mayer, 2001); (iii) the "single concept principle" that points to one single matter of fact, term, or concept. Different aspects can the be treated in sequence step by step. In particular, this can be helpful for teaching basic principles. Examples dealing with fundamental principles concerning waves are shown in Figure 11. On the left hand a set of physical terms is shown. Clicking on a term starts playing a short video clip to illustrate the underlying principle.

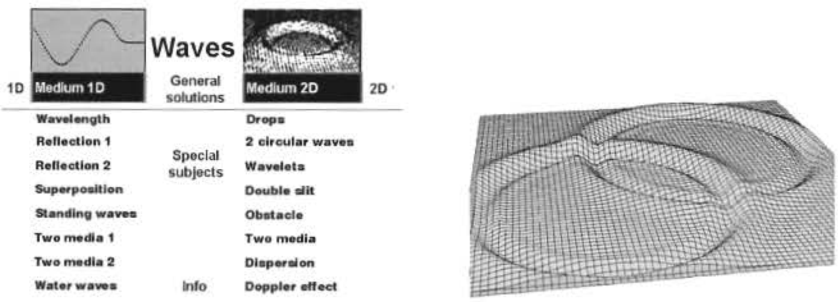

Figure 11: A List of Applications Dealing with Wave Phenomena (A) and an Example for an Accentuated Phenomenon: Inter-penetrating Circular Waves / Principle of Undisturbed Superposition (B).

A Brief, Simplified Summary and Outlook

Use multimodality, multicoding, and interactivity to foster deeper learning, and

- assist cognitive flexibility by enabling the flexible use of various representations, change the superficial appearance of objects, use the supplantation principle to establish cognitive connections, and link details using hypertext / hypermedia

- help to build mental models, use multiple representations to activate existing concepts, to construct and integrate components, to focus on special aspects, or to illustrate the interplay of settings
- use multimedia to implement ideas of situated learning and anchored instruction, build connections to authentic settings, and use interesting and challenging simulations and modelling systems
- structure fields of knowledge by using hypertext as well as more visual displays, like mind maps, concept maps, reference maps or charts that modern media can make available in flexible ways
- be aware of the necessity to avoid cognitive overload, implement features to control the flow of information, provide plain user interfaces, and offer further guidance, perhaps even by using a workbook.

On the basis of the theoretical assumptions described, a specific multimedia programme and learning environment was designed. Figures 7, 8, 10 are taken from these applications. See Girwidz, Bogner, Schaal and Rubitzko (2006, present issue).

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