Visual Communication in Web-based Learning Environments

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ABSTRACT
Enhancing World Wide Web developments, the new opportunities for interactivity and flexible access to various media challenge the traditional experience in shaping learning environments for online education. The major difficulties are related to the appropriate development of learning environments in order to achieve a final design, which improves the motivation and the result, and serves the communication between author and learner most beneficially.

Based on general research observations on pictures, signs and media, on opportunities and limitations for new aspects of presentation and interaction with information this paper reflects on their implementation for e-learning performance with the aim of improving the learning efficiency of students. Dealing with this matter, the paper describes important guiding principles for shaping visual communication aspects of developing appropriate interface design in engineering learning environments. Good interface design allows the user to accomplish a variety of tasks, to operate intuitively, with ease of navigation. At the same time, it can gain his attention, irregardless of the information being communicated. Furthermore, the paper discusses an approach of learner-centered design along with layout considerations.

Keywords
Learner-centered design, User interface design, Screen layout, Hypermedia, Instructional design.

Introduction
The development of learning systems is one area that fundamentally requires consideration of cognitive aspects because of the learner’s importance. On the one hand, the support of intelligent interaction between system and learner evolves to a communication issue between author and learner. On the other hand, as with any application, the learning system design acts as major factor in the learner’s perception, satisfaction, and result. Finally, the effectiveness of web- and computer-based environments, which focus on self-controlled learning activities, depends on the author concerning the accessibility and the transparency of the information contents and on the learner concerning the personal conditions and recognizing ability respectively. (Klett, 2001a) Therefore, the problem with shaping learning systems originates in the communication irregularities between author and learner. It can be solved by a competent user interface design, which requires formal studies and perceptual understanding, including aesthetics, graphic form and structure, interactivity and navigation concept development and visual organization methods, in order to solve communication problems.

The proposed framework for engineering learning environments includes a developing strategy for applying the theoretical findings. It is illustrated with examples drawn from the web-based virtual learning space Educational Media (Ed-Media) for real-time interactions, which is preferentially designed for university students in media engineering courses. The learning design concept is intended for the adaptation of mandatory and optional subject matter in lecture courses. It concerns the content-based and advanced graphical implementation of knowledge subjects by taking into consideration learner-beneficial aspects. With respect to findings in instructional, interface and visualization design, the primary aim of the highly interactive modular and open-ended learning environment is to motivate, point visually out the relevance of the knowledge to be studied, and emphasize self-controlled learning activities by a suitable range of ‘modeling’ (Niegemann, 1998) to reduce the cognitive overhead.

Therefore, all the attention is being focused on the content structure, the content presentation, and the learning control, which have recently shifted the accent on the research on knowledge construction, thinking and training. The learning design concept of the virtual learning space Ed-Media enables the exploration of the subject domain for educational as well as informative goals, enhances the motivation, and efficiently supports the...
learning and imaginative processes of different learners by offering highly interactive communication capabilities (e-mail, chat, newsgroups, discussion groups, etc.).

Hypermedia-based learning environments offer an extremely powerful way of accessing, organizing, presenting and interacting information. Reflecting on their implementation for e-learning performance aimed at achieving the learner’s optimal information acquisition, the next sections discuss essential aspects of learner-centered design along with visualization, interactivity, navigation and design considerations, which are related to shaping appropriate visual communication for learning environments.

**Communication aims and design**

Insufficiencies of concepts, consistency, screen layout, interface design, navigation strategies, low-level of interactions can result in inadequate learning environments. Consequently, the development of a learning environment, which learning design concept deals with these problems, so that the final application improves the motivation and the results, is coupled with the investigation of human visual and acoustic perception. Since we can never hope to exactly transfer the communication aims between author and learner, it is essential to know the fundamental characteristics of acquiring knowledge and imparting knowledge and to make use of them in right perspective. Such knowledge will also support the design of efficient navigation through the learning environment. It is well known that individual differences in learning behavior are large. However, effectively designed learning environments can be used to enhance the motivation and to enlarge the learning strategies on an individual basis.

In order to expand the communication capabilities in a learning environment, it is essential to consider two primary aspects in the user interface: information presentation and information access. Pursuing this aim, the general design of hypermedia-based learning environments should be viewed in its own unity of concept and design modeling stressing on the user interface as a communication area. Related to these explanations, the presented virtual learning space Ed-Media benefits from research on both the consideration of human visual and acoustic perception in the learning interface and the sufficient visualization of multidisciplinary contents for engineering educational activities. Visualization concerns the visual representation of data, objects, and systems in order to enhance communication and thus understanding. The visualizations in the Ed-Media content library contain 2D and 3D models, 2D and 3D animations, Virtual Reality Worlds and simulations, which effectively support the imaginative process, and the spatial knowledge acquisition, allowing the learner’s immersion in a hidden world. Thus, it appears that they can improve the learning efficiency of different learners. Learning efficiency can be defined as the sum of knowledge and skills acquired by instruction or study that improves performance divided by the sum of all the information delivered during the learning process. The construction of effective visualizations requires familiarity with the main tasks of visualization techniques, which are described in the next session. Those involved with the perception of visualizations often speak about cognitive visualization, which main objective is to study and consider factors related to human perception and ability to identify objects visually. The focus of the research is on facilitating the development of user-centered models to enable the interactive design, exploration and manipulation of multiple represented information. The primary focus of the implementation efforts is on applying the theoretical findings to the virtual learning space Ed-Media and developing an optimized learning environment.

**Visualization tasks**

Visualizations are more meaningful when their composition, layout, lighting reflect common perceptual aspects. According to Stary (1997), important aspects, which should be considered by constructing of appropriate visualizations, are:

**Motivation:** Visualizations tend to cause attention and inquisitiveness due to the presentation of facts by sensuous stimuli. Further, they can provoke an emotional response (laugh, association, etc.).

**Memorizing:** Due to linking of text elements with image elements, on the one hand, and causing emotional responses, on the other hand, visualizations can support memorizing information and remembering of information.

**Form / Structure:** Due to the perception of visualizations as a whole, they provide a detailed overview of the facts, and thus they effectively support orientation problems. Additionally, visualizations can more suitably
represent cross-references and relationships between the particular elements of the objects compared with the sequential presentation of oral or written information.

**Explanation:** Visualizations are the most important aid in providing information, if oral or written information cannot be fully presented, the matter becomes multifaceted, or an issue should be explained in general or in detail.

In keeping with the research focus, the decision was taken to create a unique highly interactive learning environment, which integrates various dynamic interactive visualizations, Virtual Reality worlds, and simulations. The visualizations in the virtual learning space Ed-Media enable the learner to explore the subject in an active way and support his knowledge constructing process. Moreover, they provide external support for mental representations and allow to modify parameters and therefore to test assumptions, to change viewpoints in animations and Virtual Reality worlds – a process, which could be not represented by a limited number of static visualizations.

Constructing the visualizations in the virtual learning space Ed-Media, the work is concentrated on the most remarkable parts of the representation. Visualizations, which guide the viewer’s eye to unimportant parts of the image, may cause the overlooking or ignoring of significant parts. Possible features to focus the human eye could be brightly or highly saturated color parts, moving or changing options, accentuated boundaries, etc. **Figure 1** illustrates the foreground / background differentiation: the yellow colored microphone capsules of a stereo microphone give the impression to be in the foreground compared to the gray colored common housing. Moreover, the highly saturated yellow color concentrates the eye on the most important part of the stereo microphone illustration - the capsules.

![Figure 1. Beneficial color effect using foreground / background differentiation](image)

It is evident that attention to perceptual principles is essential to the construction of effective visualizations. Therefore, an additional important aspect of creating visualizations for visual communication aims that is being used in the virtual learning space Ed-Media and can be generally used to promote instructional outcomes is the consideration of context relation and association. Gnoyke (1997), drawing on earlier studies, stresses the quicker recognition of related objects compared with objects, which are out of context. Consequently, the recognition of image information is depending on both the details of the representation objects and the context. **Figure 2** demonstrates a possible way of context embedding by tactically, transparently using different media for learning about complex configurations.
Gnoyke (1997) advances the idea of a transfer of the image information into a mental format. The learner applies this format to the construction of a mental representation. Due to the relation of association to the learner’s prior knowledge, its importance for the processing of information is undisputed.

It is evident that the process of understanding, memorizing and using visualizations affects many aspects of the processing of information. It requires plausible image contents and transparent concepts of the image objects because visualizations include an informative as well as an associative outcome. Bower et al. (1975) give a precise view on visualization: “it means getting the „message“ behind the medium”.

Creating more intuitive and valuable visualizations concerns recognizing and realizing the main tasks of visualization techniques. Nevertheless, in order to foster learning in students and to ensure meaningful learning, it is crucial to integrate also various interactivity features, which allow the learner to individually explore the learning space. The next section focuses on central interactivity tasks and their implementation in the virtual learning space Ed-Media.

**Interactivity tasks**

Interactivity refers to the user’s communication with the learning system. It is important to note that interactivity presents not only a multimedia feature of a learning system but it has a key role for the learner’s processes of information access and information acquisition. The learner and the system communicate through the use of various controls implemented by the learning system designer or author. Choosing the right controls means the designer has to deal with industrial as well as corporate standards, and to focus on learners’ needs.

Schulmeister (1997) calls the space, enabling interactivity and data access, the event space. With reference to Giardina (1992), he differs between the physical interactivity and the cognitive interactivity. Giardina (1992) draws attention to the learner with his own motivation and calls for consequences in dialog quality during interactions. Viewed in this light, the content of the educational software applications and the relevant objects increases in importance compared to the manual activities.

Nevertheless, the implementation of functions tailored to the learner’s sufficient and systematic interacting with the e-learning environment must be considered. Depending on the interaction, Dzida (1995) classifies interaction...
points into different types of interaction: function selection (menu), object selection (lists), object manipulation (input and modification masks), processing functions. The interaction points are accessible to the learner in the presentation interface. An interaction type can be offered with different appearances, for example dialog windows, command buttons, option buttons, check boxes, list boxes, tree views, etc. For example, the dialog windows serve the direct communication of the learner with the objects of interest. Along with the buttons, which represent different user strategies, dialog windows are the primary way that users take action within the virtual learning space Ed-media. The dialog windows are characterized by the following properties: structure (menu with hyperlink entries or text input), geometry (adapted position, size, and layout), presentation (foreground and background color with appropriate font color), application linkages (selected menu entries send messages to the relevant window objects associated with the menu; user-relevant inputs and sessions can be stored in the database). In order to allow the learner to have a consequential opportunity for motivation-based self-controlling of his own learning paths, dynamic self-regulating and content manipulating, various user strategies have been included (thumb-tabs, footprinting, annotations, communication options, etc.). (Klett, 2000)

Constructing and designing 3D learning environments with Virtual Reality components, the task to develop the graphical user interface with the appropriate interactivity options is more difficult. Providing a variety of interaction features and metaphors respectively, divided by Kloss et al. (1998) into navigation (free moving through the Virtual Reality world), manipulation (direct treatment of the objects), activation, retrieval (search of information about particular objects or their relationships) and presentation (adjustment of the Virtual Reality world), the learner has a situation-related access to relevant information and the possibility to freely move through the learning space. (see also Section Designing a beneficial learning system) Moreover, the 3D user interface bears the responsibility for achieving a most effective reality-close impression of the material to be studied. The most important goal in the design of the interactivity issues is to overcome the fundamental difficulties learners have in understanding and handling the content. So looking at a learning system from the point of view of its usage, useful navigation strategies are needed, in order to facilitate the learner in his navigation and orientation tasks. Therefore, the next section is concerned with a pattern including techniques to optimize learning environments by improving the efficiency of navigation features.

**Navigation tasks**

Navigation refers to finding the relevant information in the learning system. The physical interaction aimed at navigation among contents, which is controlled by the learner’s goals and intentions, is located in the semantic level containing the data and the information. Schulmeister (1997) calls this semantic level the meaning space. It can be accessed via the event space. Astleitner (1997) describes the continuous access to nodes and the information selection as the major components of the learning process. He distinguishes between the following types of information access:

- **Search** (entering a search word or a combination of search words causes a system feedback if there are matches in the relevant nodes or not),
- **Navigation** (strongly connected with providing of associated links, which increase the linearity of the information system - the more navigation options, the more linear becomes the original structure),
- **Browsing** (includes an explorative information search, which can be designed more or less goal-oriented).

With reference to Schulmeister (1997), Astleitner (1997) and Klett & Repschlaeger (2000) the main user strategies for navigation that improve the learner’s comprehension and enhance the learner’s motivation can be summarized as follows:

- **Glossary** (aid to search for unknown terms),
- **Graphical illustrations of relationships between important ideas and / or terms**, 
- **Access to linked nodes containing important information**, 
- **Permanent display of the current location in the learning space**, 
- **Access to nodes with alternative presentation of the node content**, 
- **Bookmark management** 
- **Use of focus mode** (supporting the learner in solving navigation and orientation problems and facilitating the context abstraction process),
- **etc.**

Each of the three fundamental aspects of constructing a user-friendly learning environment - visualization, interactivity, and navigation tasks, defines a particular element of the desired functionality. By integrating a variety of user strategies for navigation and interaction, the instruction and learning experience can improve. Engaged learning allows students to activate their own learning goals and explore relevant knowledge resources.
By integrating synchronous and asynchronous communication (chat, discussion groups, e-mail, etc.), learning can be enhanced if the attention is being focused on the efficient presentation of the material to be studied, on the required learner’s interaction and the resultant interpretation of the material. In this case, the learning environment enriches the learning process providing the feeling of having personal interaction with the tutor and among learners and creating an active learning situation by engaging the learner in crucial communication tasks.

In hypermedia-based presentation and learning systems, the precise decision on integration of interaction opportunities and the correct goal-oriented selection of media formats for content presentation are the cruxes of the matter. This problem, which was originally a design problem, includes adequate decisions on content structure aspects of the learning environment and on specific human factors related to the cognitive information processing. A solution of the dilemma is designing a beneficial user interface that should enhance the individual motivation and serve the communication between author and learner most advantageously. Frey and Soloway (1987) state that the user interface is particularly important for educational software because it must provide an entry to the content domain and it must be sensitive to the general skill and developmental level of the user. With this in mind the next section presents evidence for user interface design related to visual communication aspects, especially for 3D learning environments with real-time presentation.

**Designing a beneficial learning system**

Creating learning systems, it is frequently not easy to decide what is the nature of the preferred transfer of teaching and learning, how the vision could be given life or what media would show our progress toward that desired state. Considering prior knowledge (external consistency) and experience (experience consistency), the way of placing the various media elements (text, sound, static and dynamic illustrations) and the interaction elements, which are simultaneously the visual communication elements for dealing with the application (internal consistency), presents an essential part of the navigation through the information space and the orientation in the learning environment.

By linking various bodies of information, the hypermedia base should support the learner in acquiring and searching information, exploring relationships, categorizing contents, defining plans and setting aims. Simons (1992) summarizes correctly these theoretical explanations. He points out that effective information acquisition follows by acting with the subject matter (active) in the determined context (situated). New information will also be linked to the prior knowledge (cumulated) and structures will be built (constructive). Learning is most efficiently achieved when the learner knows his aim, pursues it (purposeful) and competently controls his own acting (self-controlled). The development of a learning environment includes the capability of integrating self-controlled learning as well as an acceptable range of ‘modeling’ in order to reduce the cognitive overhead caused by the definition of relationships among linked documents. However, the practical consequence is that learning environments should be viewed not implicitly as teaching tools, but increasingly as learning tools. Over the last several years, the research on construction of the learning process has mainly concentrated on creating the activity basis, on the mental operations as well as the definitions’ settings in instructional design. By successive interacting with the subject matter, the learning model has to consider the conditions that allow the learner to accumulate new information to his own prior knowledge achieving mental structures for efficient use in different fields of knowledge.

Therefore, the task of designing the user interface evolves into the task of creating the conditions for consistency, harmony, and unity. The user interface bears the responsibility for quick orientation and suitable gain in attention. An important aim is creating an intuitive interface, which should involve cognitive, structure and layout considerations. In the following sections the important role of these aspects and their implementation in the virtual learning space Ed-Media are described.

**Cognitive considerations**

Dealing with hypermedia–based learning systems, individual learner-relevant sequences emerge in consequence of the various paths for reaching an information node. Taking into account this fact, a deep cognitive processing along with recurring review of the subject matter could be achieved. Moreover, a context-related embedding of knowledge is maintained. Information nodes in various media formats (text, static illustrations, 2D and 3D dynamic illustrations, Virtual Reality world, sound) support the learner in handling a variety of reality-close presentation forms in the user interface. They also allow the learner to create and extend the ability in competent situation-oriented acting.
As Jonassen and Grabinger (1990) point out, the learning processes that seem to be best aided by hypertext / hypermedia systems comprise: search of information, knowledge acquisition, and ability in problem solving. Duchastel (1990) gives a precise observation of cognitive processes during the information acquisition. He distinguishes between browsing (relatively free moving through the information space focusing on one’s own interest and motivation), searching (goal-oriented pursuing of links by logical evaluation of their signal effect), integrating (relating new information to prior knowledge), and angulating (considering new information from different points of view and under varied conditions). The processes browsing and searching, and integrating and angulating respectively address different information processing levels. Browsing and searching are strictly connected with the technical navigation concept. Integrating and angulating refer to the internal processing of distributed information.

Spiro and Jehng (1990) look at the hypermedia features of information presentation and access as conceivable options for supporting advanced learning in complex heterogeneous domains. The web of nodes and the relationships between these instances allow domains’ crossing and domain analysis from different points of view. This is the way to recognize context-related meanings and irregularities, and to build the ability to apply existent knowledge to new situations and subjects, which signifies the expert’s cognitive flexibility in heterogeneous domains. Mayer (1996) postulates that activating prior knowledge makes new information more meaningful and easier to learn. Possible ways to activate prior knowledge could be integration of advanced organizers, evaluation of learners’ knowledge by the tutor, use of chat rooms, etc.

It is evident that the modern theories of knowledge, which outline the learning process as a web of organized and interlinked concepts, consider hypermedia-based systems as leading techniques for knowledge acquisition, construction and imparting. In the virtual learning space Ed-Media, these theories served as an adequate source for the beneficial learning model targeted to the adaptation of mandatory and optional subject matter in lecture courses. The conceptual model unites the mental models of active and passive learners who have different habits of working with learning environments (Klett & Schade 2001). In spite of the assumed students’ stock of metacognitive learning methods, the relevant subject matter being studied is largely unknown. There is a need for expert knowledge for individual learning situations. Therefore, the model should stress on the contents and take into consideration the learner’s active knowledge constructing process, as well, in order to allow the adaptation of selected contents for reaching self-determined aims by embedding these contents in prior knowledge.

**Structure considerations**

Assuming the special case of the passive user, the relevant subject matter being studied could not precisely be explained. Considering this fact, the efficiently designed highly structured menu in each module, included in the content library of the virtual learning space Ed-Media, leads to the desired results helping to access the basic information of the knowledge domain. But the flexible access to hypermedia information in various depth always holds a disorientation problem. By the assumption of a sufficient motivation, this was the reason for the initial requirement to exclude from the beginning the disorientation in hypertext during the conscious learning process or to reduce it appropriately. Therefore, the proposed model for adaptation to the subject matter is based on a general interlinked hypertext structure, which contains hierarchical and linear structures as subsets (Klett, 2000). Both of these substructures, used separately or jointly, dependent on the particular aims, are accompanied by a framework for the learner’s construction of new knowledge including the acquisition of new structures coming up due to construction of new nodes and linking of these nodes with each other and with existing nodes. The balanced model reflects the findings in hypermedia usability of large environments with numerous cross-references regarding cohesion deficit and the resultant cognitive overhead due to lack of context described by Jonassen & Grabinger (1990).

The structured definition of documents carries built-in concepts of modularity and abstraction. Therefore, user interfaces require consideration of the human ability to memorize in the short-term and the long-term memory and to suitable support the knowledge transfer from the short-term into the long-term memory. On the one hand, this problem refers to the granularity of documents. Patel and Kinshuk (1997) also consider granularity from an interface design viewpoint. They decompose learning tasks into small components at varying levels of granularity with the perspective shift enabled through the user interface. On the other hand, this problem signifies the cognitive overhead. Thus, it is connected with the hypermedia facilitating functions like advanced organizers, history, search of information, annotations, etc. Placing a wide range of orientation aids guides the
learner through the information space and facilitates the use of the interface and the content exploration. *(see also Section Navigation tasks)*

**Layout considerations**

The layout considerations should ensure unity and harmony across the presentation of the learning system (Klett, 2001b). The established screen partition into three horizontal functional parts (identification area, learning area and control area) described by Strzebkowsky (1997) and shown in Figure 3 served as a basis for further development presented in Figure 4.

![Figure 3. The established learning interface according to Strzebkowsky (1997)](image)

The most important objective in engineering education is the visualization of details, complex structures, processes, etc. Targeted to avoid the learner’s cognitive overhead and the layout overload, and to visually accentuate the significance of each medium, the offered subject matter is divided into a text and an illustration structures. The illustration structure incorporates 2D and 3D static illustrations, 2D and 3D dynamic illustrations, sound illustrations, and a Virtual Reality world as a real-time illustration, which can cover Virtual Reality animations, too.

The identification area displays the viewpoints of the Virtual Reality world to be studied. They have to accurately reflect the content and the context of the studied domain. Their meaningful appearance helps to prevent the feeling of being lost in hyperspace.

As shown in Figure 4, the original learning and control areas run together in a unique area, which consists of four functional parts (text, static/dynamic/sound illustrations, Virtual Reality world and control area). The main area is occupied by the Virtual Reality world, which represents a 3D exploration menu (Klett et al. 2000). The
visually accentuated size of the Virtual Reality world illustrates its significant function as main navigation and addressing element in the learning environment. The closeness of the Virtual Reality world to the text and additional visualization area concerns the design principle of proximity supporting a permanent correspondence to the subject matter and an optimal context-based orientation in the Virtual Reality world.

Taking into account the design principle of the good continuity, the control elements are grouped and horizontally placed below the main area. Furthermore, this horizontal arrangement corresponds to the similar alignment predestined to the human field of view. In addition, the closeness of the control area to the Virtual Reality world concerns the design principle of proximity. The control elements, which simultaneously represent interaction functions, show additional information as text or illustrations only on request.

Selecting an element of the Virtual Reality world, you activate the available text and illustration structures. The description of the selected element emerges placed directly below the Virtual Reality window supporting related recognition and sufficient eye movement. Significant descriptions helpfully avoid disorientation problems in hyperspace. A reversible invisible making of irrelevant elements provides transparency to desired elements of the subject domain.

The location of the text and the illustration structures assumes both the cognitive propinquity of accompanying text medium, which supports the imagination process by studying the illustration, and presenting medium to each other and the importance of text and visualization expressed in the vertical arrangement.

The specific graphical concept illustrated in Figure 5 maps the presumptions of the cognitive, structure and layout considerations onto the learning interface.

![Figure 5. Example of the 3D learning interface (module Visual and Acoustic Perception)](image)

The illustration shows a screenshot of the Virtual Reality world of the Scala Tympani and a visualization of the traveling wave along the Cochlea supporting context-based learning. By combining different representations, the
complete e-learning application facilitates the learner in determined situations the access to information in various depth and in multiple dimensions (space and time).

The resultant visual balance and visual flow help to guide the learner in his navigation and orientation tasks. The design of the included media elements should fit into this framework in order to achieve a corresponding design for learning activities, which enhances the individual motivation and serves the communication between author and learner most advantageously.

**Conclusion**

The development of an intuitive user interface is a central issue in learning environments. The user interface concerns the development of a learning model that emphasizes the learner’s active construction of concepts and knowledge rather than passive acquisition of factual data. Integrating a variety of reality-close presentation forms and combining miscellaneous media formats into an author’s defined beneficial user interface, hypermedia-based learning systems are able to achieve an interactive presentation due to structuring, organizing and context-based linking of contents. As an aid in impressively presenting new concepts and approaches, multimedia, hypermedia and Virtually Reality techniques can usefully support learning processes of exploration and discovery.

Dealing with this matter, the paper has presented the basic design of the virtual learning space Ed-Media, particularly with respect to presentation and interaction with information. The proposed explorative learning approach covers dynamic illustrations as a Virtual Reality world and linked 3D animations to enhance the learners’ imaginative and learning abilities. It allows the learners to freely move through the virtual world, to experiment with its elements, and to seek for help support, textual information, or linked animations. The implemented interactivity features support event synchronizations and dynamic course changes of the Virtual Reality scenarios by user interactions. Due to the appropriate learning design concept, the virtual learning space Ed-Media represents a flexible basis for improvement of the individual learning process and result.

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