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Specific help devices for educational hypermedia

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Abstract This paper examines the issue of help devices for students in hypermedia environments according to the learning context and, more precisely, according to the cognitive processes involved in that situation. The argument is based on a criticism of the level of generality of traditional help systems which are mostly concerned with user–system interaction. Three main types of learning situations are described: learning-by-doing, learning-by-instruction, learning-by-exploring and the main cognitive processes involved in these three situations are explored. From such descriptions, specific types of help devices are discussed and some perspectives relating to the design and evaluation of educational hypermedia applications are suggested.

Keywords: Courseware; Ergonomics; Guided discovery; Help; Hypermedia; Instruction; Secondary; Student-centred

Introduction

The design of help devices for students is a central issue for creators of educational hypermedia particularly as educational applications are as working environments in which the student is helped to do something which is supposed to lead to learning rather than as tutors or teaching tools.

When a student uses educational hypermedia to learn contents (e.g. concepts, skills or procedures), there are two interaction levels: computer–user interaction and contents–student interaction (see Linard, 1995 for a detailed discussion). Help devices are focused on the *use* of hypermedia (considered as an elaborated electronic document), rather than on the learning activity *per se*. Hence, the design of help devices seems to be a technical matter since there are several tools for presenting content, for locating the user in the hyperspace and for searching for information. There is also extensive literature where these tools are presented and discussed (for example, the Proceedings of the ACM's CHI conferences like CHI, 1998). But when these help devices are used in educational hypermedia environments, some paradoxical effects may occur. The help can turn out to be difficult to understand and some research studies

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suggest that help devices for comprehension or for locating information can have a negative effect on learning. For example, representing the relations between the contents of concept maps can make the material more difficult to understand for novice students (van Oostendorp & Hofman, 1998).

This paper claims that one of the problems raised by help devices is the level of generality in their definition and the fact that they focus on the computer-user interaction. It is argued that help devices must initially assist students in their learning activity (i.e. student-content interaction) in ways that relate to the learning in progress.

It is generally admitted that in hypermedia design there are three main steps (see, e.g. Fraïssé *et al*., 1996 or CACM, 1995)

- a contents or concepts analysis and their structuring;
- design of the navigation; and
- the interface design.

Hence, in educational hypermedia design, one can consider that navigation design corresponds to 'learning situation design' and that interface design should take account of results from cognitive and educational psychology (Punyashloke *et al*., 1996). But how can such results be used to design effective educational hypermedia? So far the debate on educational hypermedia design has been either general (Stanton & Barber, 1992; Jonassen & Wang, 1993; Tricot & Bastien, 1996) or restricted to specific areas of learning (e.g. Punyashloke *et al*., 1996).

One of the main problems in designing educational materials is that there is no generally agreed framework relating types of materials and interventions to various learning goals. Learning goals can be described in terms of knowledge to acquire (concepts, structures, skills or procedures), but these goals may not be specified at the same level. For example, a schema can be a skill, but also a concept which can lead to different implications for learning (van Lehn, 1991).

This paper tries to describe learning situations according to the main cognitive activity which is involved. Specifically, *learning-by-doing*, *learning-by-instruction* and *learning-by-exploring* are considered and the implications of each for hypermedia design are explored.

Learning-by-doing is a knowledge acquisition approach (that may involve procedural as well as declarative knowledge) where the students have to find their way towards a goal, for example, the well-known Tower of Hanoï problem (Anzaï & Simon, 1979). However, in many learning-by-doing situations, where documents are used to present instruction and information, students' search activity involves hypothesis testing and solution or explanation building (Sweller & Chandler, 1994).

Learning-by-instruction occurs when an expert or a teacher transmits some new knowledge to students who, in turn, are expected to understand what is explained. The new knowledge may also be contained through in materials and illustrations (e.g. in lectures or as self-study by reading). From such prescribed narratives, students try to incorporate the new material into their pre-existing knowledge and this enables them to answer questions and generally use this new knowledge. Thus, the teacher's task is to help the novice to appropriate this information and transform it into knowledge

(Kintsch, 1986; Mannes, 1988). It is generally admitted that concepts and skill acquisition can be the learning goals of this scenario but learning-by-doing techniques are needed to consolidate skill learning (Anderson, 1983; Byrnes, 1992).

Learning-by-exploring requires students to achieve more general goals or solve problems where considerable initiative is given to them. Students have to specify their task in detail and to seek, find and evaluate the relevance of content in relation to their goals. Hence, students have to create a concrete action plan, perhaps analysing the goal to create subgoals and, under this framework, seek for, compare and understand information and evaluate the relevance of the content.

This paper makes the hypothesis that educational hypermedia can support these three types of learning situations but the design requires different approaches to provide help for each type of learning activity.

Approaches to providing help

Learning with hypermedia

Hypermedia are in effect, documents or organised collections of documents. They were conceived by Bush (1945) and Nelson (1965) as computer-supported documents (not software or databases, as described by Conklin, 1987.; Martindale

(1993) provides a good discussion of this point in the field of education). A document is considered to be structured material that enables the user to 'build sense'!

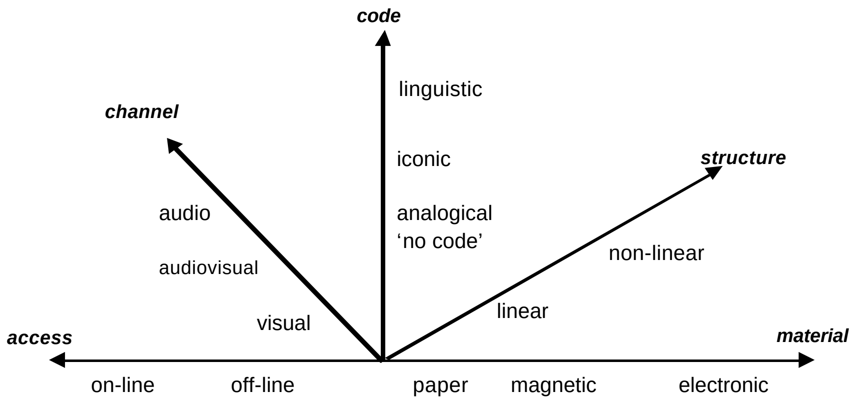

Fig. 1. What is a document?

Hypermedia are electronic materials where the communication channel can be audio, visual or both; the code used can be linguistic, iconic or analogical (e.g. sounds, pictures, dynamic pictures); the structure can be linear or nonlinear (see Fig. 1.).

Many researchers claim that learning environments and can be improved by hypermedia. For example, Lowe (in press) reports that dynamic graphics make phenomena more understandable and Mayer & Sims (1994) claim that text-picture integration improves comprehension. Some point to the great possibilities offered by multiple information sources being available (Britt *et al*., 1996) but the same authors and others (e.g. Dillon, 1996) note that when the students have to seek information in complex hypermedia they can be diverted or become 'lost'. Students have to manage their 'information seeking problem' without the aid of a restrictive framework which structures traditional learning. It also seems that processing the information or rhetoric structure of hypermedia documents is more critical and more difficult than for traditional documents.

Hypermedia is not just a way of improving well-known learning situations. It can also provide new learning environments. One approach is to provide a 'criss-crossed conceptual landscape' (Spiro & Jehng, 1990) where students are able to revisit the same material from differing conceptual perspectives by traversing different but connected routes. Such hypermedia, it is suggested, allow the development of non-linear, associative links between materials that make this criss-crossing approach explicit (Swan, 1994). Jacobson & Spiro (1995) show that this approach improves knowledge transfer rather than purely memorising facts. They propose (p. 301) hypermedia learning environments '. that present the instructed knowledge by explicitly demonstrating critical interrelationships between abstract and case-specific knowledge components in multiple contexts will help prepare students to use knowledge in new ways and in new situations'

Others believe that educational hypermedia should reflect the structures of human memory and that by empirically deriving and then mapping the semantic structure of information onto hypermedia, and explicitly illustrating that structure will result in greater changes in the knowledge structures of the students (Jonassen & Wang, 1993). These authors have designed educational hypermedias that imitate experts' semantic memory in different domains and propose situations where the students have to explore and read the documents, answer questions and solve problems. However, they provide little evidence to show the efficiency of this approach.

Other researchers (e.g. Jacobs, 1992) argue that hypermedia merely provides new clothes for old educational approaches. Discovery-based learning, for Jacobs, has a long history from Socrates to Dewey, Bruner and Papert. According to Jacobs, the principal attraction of hypermedia is that it lends itself to nonsequential educational approaches since it encourages the free-association characteristics of human thought. But Jacobs also notes that free browsing is not, in itself, an efficient learning method and 'getting lost in hyperspace' can be a fundamental obstacle to learning-by-exploration using hypermedia.

Some researchers consider that hypermedia is a good medium for self-directed learning: 'If learners are able to choose how the information and instruction is presented to them, in the manner that best suits their own style of learning, then the whole process may be more efficient' (Stanton & Barber, 1992; p. 149). In an empirical study comparing learning with linear and nonlinear materials, they show that hypermedia allows for different levels of prior knowledge, encourages exploration, and allows students to adapt material to their own learning strategy. Moreover, several studies (e.g. Forrester, 1994) note that, even if learning with hypermedia does not result in better performances, students seem to prefer hypermedia-based learning.

Many of these ′new directions' which use educational hypermedia have much in common and can be called ′learning-by-exploring′ environments. Hence, in many such situations the student's activity is an ′information searching / problem solving′ activity. The problem / information space to be explored is mostly a documentary though many of the potentially available sources will not be processed. This implies that the student must formulate a goal representation as well as a ′browsing′ or ′information seeking′ strategy. Goldman (1996; p. 20) notes that this kind of learning requires that the students *'organise, regulate, manage, and evaluate their own knowledge acquisition processes*'.

At first sight, learning-by-exploring situations seem to use a number of cognitive processes that are present in learning-by-doing and learning-by-instruction. It is now appropriate to consider in more detail the cognitive processes involved in learning-by-doing, learning-by-instruction and learning-by-exploring in order to define help approaches as a 'means to facilitate the cognitive processes involved'.

Learning-by-doing environments

In these situations students have to interpret 'instructions' that represents the task and identify the relevant components. For example, learning-by-doing may involve analogical transfer: students try to use a well known solution in a new situation that they considers similar, i.e. they mobilise pre-existent knowledge depending on their elaborated representations and categorisations. The students explore actively the task / information space and may modify their representations based on feedback. They may then formulate hypotheses (Sweller & Levine, 1982; Pierre, 1995) and test them as they proceed with the task. An important characteristic of learning-by-doing is repetition and practice in similar or related task situations. Another important requirement is feedback following students' actions which is necessary if students are to evaluate their own performance.

Learning-by-doing and the use of hypermedia

Many researches have studied different ways to help students in learning-by-doing. Some of them have focused on the design of materials (Mayer & Anderson, 1992; Sweller & Chandler, 1994; Sweller *et al*., in press). They have shown that:

- many problem solving strategies such as means-ends analysis, while permitting problem solution, can interfere with learning;
- many common instructional techniques require students to attend to multiple sources of information that must be semantically integrated;
- some forms of redundant information (i.e. information not directly needed for the current task) can result in negative rather than positive effects for some students;
- instructional material amenable to the split-attention effect can be improved by presenting some of the material in auditory form;
- the cognitive load imposed by instructional techniques is most serious when dealing with materials that incorporate interacting elements that must be learned simultaneously rather than successively.

Hence, the design of instructional materials is important as it guides students' information processing and help may consist of pointing out the features that assist an effective representation or categorisation of the problem. According to Katz *et al*. (in press), hypermedia can provide: dynamic and graphical representations of the problem / task space; visualisation aids for complex and dynamic systems and graphical comparisons between the experts' and students' solution paths.

Other researchers (Carter & Walsh, 1992; de Vries & de Jong, 1997; Wright, in press) argue that hypermedia provides new and useful materials to support complex problem solving (e.g. in decision-making or design tasks). Oliver & Omari (1999) point out that online access allows students to ask questions, seek information, develop problem solutions and communicate with other students and teachers.

Help which should be available in learning-by-doing using hypermedia

First of all, it seems that the results obtained with classical materials are often usable in hypermedia environments. For example, strong effects on learning are claimed (Mayer & Sims, 1994; Kalyuga *et al*., 1998) by using speech to add comments on pictures and by using computer-generated animations.

However, it also seems important to manage these various information modalities and levels. Bétrancourt & Bisseret (1998) suggest that one of the problems raised by hypermedia is the processing of multiple discourse levels, either in text / text or in text / picture configurations. For example, it is sometimes difficult for the user to discriminate foreground and background information. Bétrancourt and Bisseret show that setting background information in pop-up windows does not disturb and may even improve the memorising and comprehension of information. Pop-up windows are also effective for information search and make it possible to foreground some information giving the document some structure. Further, insertion of pop up windows also makes it possible to integrate various types of coreferenced information which facilitates their cognitive integration (Sweller *et al*., 1990) and can help to reduce a cognitive overload sometimes found with paper organisers.

Learning-by-instruction environments

In learning-by-instruction students acquire new knowledge when they elaborate a situation (or a mental model) using information included in the text which relates to the task they have to fulfil, building on their pre-existing knowledge.

At the first stage, the symbolic information processing is a lexical and syntactic one which, at the second stage, is developed into a macrostructure, for example, the links between concepts or arguments. At a third stage, the structure becomes an active mental model of the situation. All these stages, which define the learning process, depend upon previous knowledge and experience.

Learning-by-instruction and the use of hypermedia

To assist the first processing stage, the designer has to use appropriate vocabulary and syntactic structures. Also, at the second (macrostructure) stage arguments should be linked using well-known schema (de Beaugrande, 1981; Waller, 1987). The third stage in which a mental model is developed concerns student knowledge and mental activity related to the theme or the situation and uses earlier knowledge.

It is useful if in learning new material, it is possibile to process the same content in different ways so that understanding is consolidated (Mayer, 1983; Dillon, 1994; Kalyuga *et al*., 1998). Hypermedia allows designers to integrate different information formats dynamically. Texts, sounds and pictures can be integrated and hypermedia also allows designers to represent dynamic and complex phenomena so that processes can be illustrated over a period of time.

Help which should be present in learning-by-instruction using hypermedia

At the lexical and syntactic stage, word definitions may appear in pop-up windows (Bétrancourt & Bisseret, 1998) or as additional speech (Tindall-Ford *et al*., 1997) thus providing a glossary of the domain. An information selection or hierarchical display of content can be developed and related to students' answers on a pretest (Tricot & Rufino, 1999). The system should also take into account students' different purposes related to the specific instructional tasks and their level of knowledge, i.e. how familiar they are with the domain. However, students will need aids to assist in navigation and in linking to previous experience.

Learning-by-exploring environments

The specific cognitive process involved in learning-by-exploring is ′advanced knowledge acquisition′ and *Cognitive Flexibility Theory* describes this activity (Punyashloke *et al*., 1996). For these authors, advanced knowledge acquisition concerns the acquisition of flexible cognitive representations that '. . . *enable the transfer of knowledge to contexts different from those that had been involved originally in the teaching of the material. Such representations increase the likelihood that knowledge ensembles can be constructed as required*' (p. 292). It is recommended that knowledge ensembles are explored from many perspectives. Spiro *et al*. (1987; pp. 187–188) use the metaphor of a ′criss-crossing landscape′ by which '. . . *the twin goals of highlighting multifacetedness and establishing multiple connections are attained*.'

Rouet & Tricot (1996) also developed a framework (the ESP model) describing hypermedia users' activity as problem solving and contents processing activities which may be used for learning-by-exploring. This model represents a processing cycle of three main stages: goal evaluation, topic selection and content processing.

Goal evaluation first takes place at the very beginning of the activity when the student has first to determine whether a solution or answer can be produced and what means should be used to reach a solution. The goal may be defined in terms of information to be acquired and then, in a learning-by-exploring task, the student may focus on methods of structuring and organisation or on processes to be applied to the information (e.g. text summarisation).

During the content processing stage, the student acquires a cognitive representation and hence an understanding of the problem task domain, but their understanding process involves a hierarchy of processing levels.

Goldman (1996) and other authors (see Ayersman, 1995 for a review) outline the important role of metacognition and for Rouet & Tricot (1998), three metacognitive processes are implicated in hypermedia use:

Plans: choosing and planning the means to find the relevant information.

Controls: monitoring the search process and verifying or judging the value of the material in relation to the task goals; and

Regulation: modifying or continuing the hypermedia activity to enhance the result (e.g. the students will relate the material to their previous knowledge and on this basis may modify current plans or decide to change the goal representation).

Help which should be present in learning-by-exploring hypermedia

If Rouet & Tricot's (1996) model is valid, then it is possible to propose educational hypermedia help that is: related to task management; related to information selection and related to understanding. Help related to task management mainly consists of assisting students to elaborate an appropriate goal representation whereas help related to information selection concerns two aspects: an identification of information categories and assistance in making a choice between those categories.

A further kind of help operates at a 'metacognitive' level. As Goldman (1996) notes, several studies in educational hypermedia argue that it is possible to improve learning by leading the students to think about their own activity, their own learning. This metacognitive level can be promoted by giving information about relationships between the hypermedia nodes or by asking questions that require reflection about the activity (e.g. in planning and decision making).

Such 'metacognitive help' might focus on the semantic relationships between the hypermedia nodes though such help can be difficult to design. There are many tools for visualisation, ranging from simple outlines to 3D graphics (Silva, 1992) and sophisticated presentations (e.g. concepts maps, with fish-eye views). However, Stanton (1994) conducted experiments which showed that concept maps may lead to poorer learning performance, lower perceived control over the hypermedia system and poorer development of cognitive structures. Concept maps seem to have, in the best cases, short-term effects on learning (Goldman, 1996) and they may add to the cognitive overload rather than reducing it (Recker & Prirolli, 1992). In contrast, Britt *et al*. (1996) have argued that graphical representations of the relationships between contents are efficient provided they are unambiguous, homogeneous, simple and represent just one kind of relationship between the contents (i.e. links have only one semantic value, one meaning). In their meta analysis of experimental studies of hypermedia use, Chen & Rada (1996) compared graphical maps and textual user interfaces. They showed that graphical maps have a beneficial effect on tasks (measured in terms of goal achievement) and on efficiency (measured in terms of time to achieve the goals). They also report that hypermedia efficiency depends on users' expertise and on task complexity ('hypermedia expert users' benefit more from hypermedia tools for open tasks, but they often spend more time on task). Kim & Hirtle (1995) also found similar effects for task complexity and users' expertise.

Other 'metacognitive help' concerns information about student activity, for example, Lin (1993) proposed:

- a notepad that students could use to jot down important ideas and explanations;
- a graphic tool that permitted students to draw diagrams of the relationships between concepts (i.e. students construct their own cognitive maps);
- a linking tool that permitted students to construct links between concepts and ideas in the text (i.e. students produce their own 'map of the material');
- an inquiry tool which students could use to highlight words and phrases whose meaning they were unsure of; and
- the option to reveal or hide annotations to the text.

However, other researchers suggest that the interest in hypermedia lies in the lack of guidance and constraints placed on students. Thus, to help students avoid getting lost, only careful design of the navigation space is needed. Suggestions include:

- the definition of *constraints* related to database structure (Tricot, 1995), in terms of 'breadth level' and 'depth level'
- the definition of rational database *organisation principles*, where the user has to understand the content organisation independently of the actual content (Tricot & Bastien, 1996).
- *dynamic structuring* where links are defined and strengthened according to the frequency of their use (Holt & Howell, 1992; Bollen & Heylighen, 1997).

Another approach consists of helping students locate themselves within the documentary space. An example of this approach is the *history list*, that is a chronological record of the nodes or addresses opened within a session. History lists can be used as a 'return' tool or a tool to locate a specific place. However, simple history lists have the disadvantage of being linear whereas the structure of the consulted documents is often hierarchical. 'Graphic structuring' history tools such as MosaicG offer a solution to this problem (Ayers & Stasko, 1997). The guided tour and even page turns are useful ways to discover the content range and organisation of hypermedia. The problem is that they either create a linearisation of the structure imposed by the author of the guided tour or use a search algorithm requested by the student. Such browsing tools therefore have their limitations.

Discussion learning situations, cognitive activities and design of help systems

Two main sources can be used in designing educational hypermedia and this paper draws on both domains. On the one hand, computer–human interaction provides design frameworks and general tools while the psychology of education provides learning theories that relate to educational practice.

This paper has argued that it is useful to distinguish learning-by-doing, -by-instruction, and -by-exploring. In learning-by-doing situations, it is noted that the design of materials can be improved by reducing the split-attention effect (e.g. by integrating different information sources or by presenting some material in auditory form); by providing analogies and information about results and by managing the various information levels involved in the task. In learning-by-instruction it is useful to include word definitions (or examples) in new formats (pop-up, additional speech); to adapt the materials dynamically to students goals through structural aids and to use dynamic representations to illustrate phenomena and to represent different contextual settings of a concept. In learning-by-exploring situations, some general help principles are suggested which focus on metacognitive reflection.

The design frameworks proposed by computer–human interaction include three main phases: contents or concepts analysis and structuring; navigation or scenario design and interface design.

For *contents or concepts analysis* and structuring, some authors stress that the hypermedia structure must reflect the domain structure while others consider that it must be less restrictive and reflect the associative functioning of human memory.

For *navigation and scenario design*, Tricot & Rufino (1999) distinguish the level of interaction methods and the interaction scenario. The interaction methods relate to the concrete and material aspects of interaction between user-student and the computer whereas the interaction scenario relates to the learning aspects of the interaction. For these authors the learning scenario for educational hypermedia has to be designed and related to each learning situation and no learning theory can provide a ′ready to use′ or universal instructional scenario.

For *interface design* in educational hypermedia, two interface design principles are important:

- An interface defines a compatibility between, on the one hand, the user’s representation (task representation and knowledge used), and on the other hand, the designer’s formalism (task representation and knowledge in the system). Gamboa Rodriguez & Scapin (1997) describe precisely how task analysis can inform the design of an interface.
- Many experimental results provide useful design principles for information display, in particular regarding space and information density, special characters, colour, typography, punctuation, video characteristics, multiwindowing of the text, relations between text and figure, presentation format, space and temporal provision of diagrams.

Finally, it seems that it is important to distinguish between different types of learning situations involved in educational hypermedia, though the three types used must be refined and described much more precisely. However, it appears that in design it is useful to consider the basic cognitive activities such as ′understanding a situation’, ′making hypotheses’, and ′elaborating a task representation′ and consider how such activities can be supported. Hopefully, this paper gives some encouragement to this approach in the design of educational hypermedia.

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