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ABSTRACT

This paper focuses on issues of representation and interaction styles that are relevant considerations in the design and analysis of hypermedia learning environments. Analysis is supported by examples from the "HUGH" series of studies involving learners in reasoning about formal hypermedia representations. The representational issues include analogical representations versus fregeian representations, multiple representations versus single representations and replete representations versus minimal representations. Analogical representations are those in which relationships in the represented entity are symbolized by actual relations, as opposed to names of relations. Another critical design issue is whether the user is provided with one representation or several, one encoding expressed in one medium or several encodings expressed in a variety of media. Another issue for consideration of representation style is a minimal design approach to prevent information overload that might occur with replete representations. Additional issues include the extent to which the imposition of additional constraints can be a useful feature and whether users learn more from exploring a representation or from building on for themselves. (Contains 20 references.) (AEF)

# Hypermedia Representations for Learning: Formal and Informal Observations on Designs and Directions



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**Abstract:** This paper focuses on issues of representation and interaction styles that are relevant considerations in the design and analysis of hypermedia learning environments. The *representational* issues discussed are: *analogical representations vs. fregeian representations, multiple representations vs. single representations* and *replete representations vs. minimal representations*. In terms of *interaction styles* found in hypermedia, we discuss *constrained vs. unconstrained* and *exploratory vs. constructive* approaches. Supporting examples from studies carried out to investigate some of the issues discussed are used by way of illustration. The paper concludes by discussing the cultural influences that are impeding the effective use of non textual representations as primary communication media.

The purpose of this paper is to outline several concepts and ideas relating to the analysis and design of learning environments, particularly those of the hypermedia variety. The paper is not meant to provide answers to the questions posed by the enterprise of hypermedia interface design, but rather to discuss certain perspectives on the questions themselves. Thus, the paper is intended to provoke further discussion about issues relating to hypermedia interface design and evaluation. While our main interest is in using predominantly graphical hypermedia representations in the learning of mathematics and other formal domains, the paper discusses issues that we believe are demonstrated to be central to hypermedia interface design.

The structure of the paper is as follows. The next section analyses some design choices referring to the nature of the representations that we use in our hypermedia interfaces. The following section then discusses similar binary differentials with respect to the style of user activities demanded by hypermedia representations. (Please note that neither section is claimed to represent an exhaustive list of topics). The analysis is supported by examples from the "HUGH" series of studies involving learners in reasoning about formal hypermedia representations (Parkes 1992a; 1992b; 1994). The HUGH systems embody constrained direct manipulation graphical and text representations of theorem proving tasks in formal computer science. Examples from the HUGH studies (one HUGH screen is shown in Figure 1) are used to illustrate the issues raised in the paper.

## Design Choices for Hypermedia Representations

### Analogical Representations vs. Fregeian Representations

The terms "analogical" and "fregeian" were used a few years ago by a leading AI theoretician, A. Sloman (Sloman, 1975; see also Hayes, 1974), long before it became fashionable to talk of "media" (let alone "multimedia" or "hypermedia") in the context of computing. Sloman's fairly abstract discussion concerns concepts at the heart of the whole business of representation. Analogical representations are those in which relationships in the represented entity are symbolised by *actual relations* (as opposed to names of relations) in the representation of that entity. A map is an obvious example of this, since spatial relationships between objects on the ground are reflected in the map (unless it's a map of the London Underground system).

Sloman (*op cit.*) also describes how mathematics teaching neglects analogical representations i.e. pictures and diagrams. We observe that a central problem with respect to analogical representations in mathematics is in choosing or designing a representation (e.g. suitable diagram, picture, etc.) that is really useful to learners. In a formal domain, the picture can become as abstract as the usual text-based notation, and in some cases it appears that one has already to understand what the diagrams refer to before the diagrams can be understood! For example, the initial HUGH studies were devoted to investigating the understanding that learners have of a direct manipulation diagrammatic representation of an abstract mathematical problem solution. The diagram was similar to that on right of Figure 1, and a number of simple operations could be carried out by the learner, such as copying significant parts of the diagram into a "store" (lower left of Figure 1), then replacing significant parts of the diagram by the component in the store. Sequences of operations that the learner performed were constrained to be meaningful steps in the proof of a theorem. The main aim of the studies was to find out if the learners themselves could arrive at a description of what these "steps" were signifying. As was demonstrated by these studies, users can happily directly manipulate abstract diagrams without arriving at the account of their semantics that the designer intended. Viewed purely syntactically, the operations were very simple, while their meaning was complex, and it required substantial mental effort for the learners to construct it.

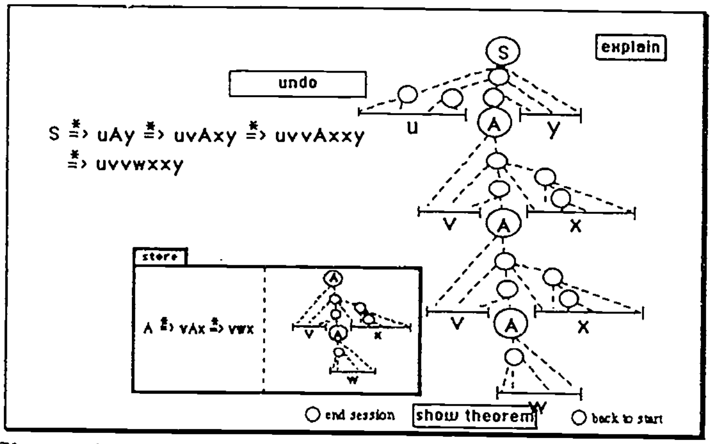


**Figure 1.** A screen from the dual representation version of HUGH

## Multiple Representations vs. Single Representations

A critical design issue is the extent to which we provide the user with one representation or several, or more specifically, the extent to which we use one encoding expressed in one medium or several encodings expressed in a variety of media. We need to be clear about why we might want to use several representations, because there are clearly different reasons for choosing to do so. For example, it may be so that everyone has a chance to understand the material (c.f. Draper's (1992) search for representations that work for all, or diSessa's (1986) call for "the equivalent of pens and paper for everyone" [p126]). It may be to provide variety for a single user, or to ensure redundancy, or to reinforce. It may be to provide access to features that one medium cannot express, or cannot express to the same degree of veracity, as another medium.

Moreover, multiple representations should exert an influence over the ways in which we attempt to assess the knowledge gained by learners. Implicit in a system that presents multiple representations is an assumption that the learner is able to reach an understanding of the relationships between the various representations. It has been argued (White, Sandberg, Behar, Mockler, Perez, Pollack & Rosenblad, 1984) that asking a learner to translate from one medium to another requires a symbolic transformation which may distort his or her comprehension. White *et al.* also argue (c.f. McLuhan) that the medium affects the message, i.e. influences the coding *processes* that the receiver of the message can apply to the message. It has been demonstrated that, for child learners at least, the medium of presentation affects what is learned and how it is learned, while the medium of *comprehension testing* may also affect the evaluation of what knowledge is acquired if it requires subjects to transform information received in one medium into another in order to respond (White and Pollack, 1985). White and Pollack's study suggests that having to perform such translations when demonstrating comprehension can decrease comprehension scores. Tacit support for this view resulted from the HUGH studies, when learners were asked to verbalise their thoughts on the meaning of the operations. Users of a version with diagrams alone (i.e. a version without the textual representation beneath the "undo" button, and on the left of the

"Store" in Figure 1) gave explanations initially expressed purely syntactically, e.g. "the diagram in the store replaces the selected part of the diagram", that only later evolved into more semantically-oriented descriptions. On the other hand, users of a dual representation version (a display from which is shown in Figure 1), gave semantic descriptions much earlier on in the session, thus suggesting that the textual representation was encouraging them to translate between the representations, the text providing links to facilitate the verbal description of the semantics of the operations. It is noteworthy that this occurred *despite* the fact that learners using the dual representation version overwhelmingly preferred to interact with the diagram - the textual representation was exerting a subtle influence that was not apparent from the learners' actions in the interface.

As yet, we lack knowledge about what are the optimal combinations of representations (and corresponding media) for given tasks and learners. Beasley and Vila (1992) suggest that future research on media should be conducted to study the attributes of media with respect to the cognitive implications of those attributes. Larkin and Simon (1987) provide what might prove to be a *theoretical* basis for assessing the cognitive implications of various media. They essentially say that we need to be more aware of the ways in which a "chunk" of information can be presented by different media, rather than focusing on the information content *per se*. One useful contribution that Larkin and Simon make is a richer model of *equivalence*. They distinguish between two types of representational equivalence: equivalence in the information *content* of different representations (*informational equivalence*), and equivalence in the information *processing* requirements (for the perceiver) of the representations (*computational equivalence*). Two representations can sometimes be informationally equivalent but differ considerably in the information processing demands they make upon the user.

The issue of the "computational cost" (to the learner) of translation between media emerges in the differences between the explanations of the users of the "diagram" *vs.* "diagram plus text" versions of HUGH. Users' misconceptions became apparent to us only when they attempted to *describe* their understanding of the representations. The dual representation users seemed to benefit from the aid given in the translation process by the presence of the textual representation, and the ways in which its own behaviour modelled that of the favoured representation for interaction (the diagram).

## Replete Representations vs. Minimal Representations

The author recently attended a conference at the Glushkov Institute for Cybernetics which is in a residential area of Kiev. On the first morning of the conference he walked from his lodgings along a main road to the conference site. He knew that the Institute was somewhere along this road, but was also aware that it was set back a few hundred yards from the road, behind other buildings, and he could quite easily pass it without realising. The author possessed a plan of the city on which neither the scale of the map nor the location of the institute were indicated. None of the streets seemed to have name plates. The author approached an old man standing by a bus stop, and used a combination of pointing (both at himself and the portion of the map representing his approximate location) to convey in a few moments the question "where am I (on this map)?". The old man spoke to the author in Ukrainian, while the author replied in English. Suddenly the old man spoke two words that the author recognised: "Glyooshkova", and "Keebernetikka" (the old man must have guessed that there was just no other reason for a foreigner to be in that part of town). The problem was solved: in a few more gestures the old man had shown the author how to get to the institute!

The striking feature of this episode was the way communication was effected using a minimal level of representation. There was no need to show the old man a video of the institute, or even a text description. Questions were asked by pointing at part of a map - the rest was done by simple gestures that seem to be more or less universal.

The above episode is relevant to multimedia and hypermedia interface design. We are often tempted to make a system "replete with different representations" (or to provide a single "replete representation"). As a reaction to this, we have experimented with systems that simplify, or *minimalise* the representations, and attempted to investigate what can be achieved by the simplest possible representation. Replete representations may simply overload the user, i.e. Aaronson and Carroll (1987) may be correct in asserting that learners are very situational and often find information useless if they cannot relate it to the solution of their problem.

In the HUGH studies users explored and described graphical representations that were supported by very little explanatory text. This is based on our assumption that before we start *adding* media such as diagrams to systems, we need to know what we can, and cannot, hope to achieve by doing so. In this we were agreeing with Draper (1992, [p177]), who says: "adding media...[to a system]...is of no automatic value - it will only be useful if someone invents a representation that fits the mind in some important way and happens to use the extra 'media'". He also goes on to say "Representations...[for]...promoting understanding are usually simplified, not enriched in complexity" [p178]. It is interesting to compare the latter assertion with the claims of the constructivists, some of whom seem to suggest that complexity may be a desirable feature (Jonassen, Ambrusso, & Olesen, 1992). Whether this is true or not, it is not useful as a design aim, because we cannot evaluate a "complex" representation against a "simple" one and say that any gains (however measured) are due to the complexity: we just wouldn't know if it was the complexity itself that caused the gain. This is especially true in terms of multiple representations, where there are so many poorly understood dimensions to complexity (i.e. the complexity of any one encoding, the complexity of the mental mapping between different simultaneously presented encodings...). In a way, our approach is not the typical one of presenting all the information to the learner, and then establishing that something is being learned. We actually say: *present the learner with the minimal amount of information, and see from this what they cannot learn; then investigate what form of information we need to add to alleviate the problem.* The initial HUGH system (a purely diagrammatic version) featured a simplified form of the tree shown right of Figure 1. We realised that learners were attributing significance to features of the tree such as its *symmetry* (unlike in Figure 1, the tree was symmetrical about a central vertical path), but this was not meant to happen. This inference, in turn, resulted in insufficiently general conclusions being made by the learners. Thus, we were able to decide firstly, that the diagram needed to be redesigned, and secondly, what sort of supporting information needs to be given to ensure that the noted problem is overcome. The minimal representation approach was a major facilitator of the accuracy with which we could identify the source of the problems that our representation presented to learners.

## Styles of User Activity in Hypermedia Representations

### Constrained Activity vs. Unconstrained Activity

Much used to be made of the freedom granted to the user in a hypermedia system. Indeed Mülhäuser (1992) compares the "anarchy" of current styles of computer assisted instruction (CAI) with the "dictatorship" of old style "presentation-based CAI". However, by definition, any hypermedia system is constrained in some senses, just by virtue of the fact that some things are linked and others are not. The issue here is the extent to which the imposition of additional constraints can be a useful feature. By this we mean more than just facilities such as "guided tours" that are an embellishment to some systems. Rather, we refer to the extent that transitions made by the user between hypermedia states are designed to reflect a more useful, perhaps *procedural* meaning than is usual with hypermedia links One such design is provided by the Harmony Space system (Holland, 1992), where novices to music can learn complex composition skills by making simple gestures with the mouse in a graphical representation, resulting in "well formed" chord progressions being played on a synthesiser.

In a slightly more trivial way, some of the HUGH systems also represent this approach, by modelling a proof, as we have indicated earlier, as a sequence of "cut" and "paste" operations on a graphical representation. The difference in the HUGH case is that there is not such an obvious relationship between operations and their conceptual outcomes (no music to the ears of the learners), which the HUGH users have to arrive at themselves.

### Exploratory Learning vs. Constructive Learning

A contemporary issue in hypermedia design is whether users learn more from exploring a representation or from building one for themselves. At the forefront of this debate are constructivists (e.g. Cunningham, Duffy, & Knuth, 1993), who see knowledge acquisition as involving the learner in the construction and interpretation of knowledge, as opposed to passive reception or unstructured exploration. The realisation of such a theory in hypermedia learning environments suggests systems that enable learners to build representations. (Though it is interesting to contrast this approach with that proposed by Laurel (1986), who asserts that people want to move around inside a representation, not make one). In a constructivist vein, Hammond (1991; 1992), describes a "knowledge jigsaw" task, where users construct an argument by linking text boxes together, with the links representing reasoning steps in the argument.

The latest HUGH study focuses on users' performance in one of two versions of a theorem proving task. One version is exploratory, and involves carrying out operations of the "cut" and "paste" style mentioned above (a display from this version is shown in Figure 1). A second version is (independently of Hammond's use of the term) called a "jigsaw". In this version users construct a graphic by dragging the "pieces" around the screen so that they "snap" together (see Figure 2). The interface is again constrained, in this case so that the pieces only actually fit together in meaningful ways. There are significant differences between the two versions in terms of the nature of the task, despite the fact that, while being predominantly either *exploratory* (finding the sequence of actions that lead to the proof) or *constructive* (building up the representation from its component parts), they have several elements in common. In the exploratory version a representation is being built, and in the constructive version exploration is needed to discover the correct assembly. Thus far, there seem to be no noticeable differences in the explanations from users of either version (this differs from the results obtained with the single *vs.* dual representation versions - see above). What *is* different is that the predominantly constructive version seems to result in the learners giving much more thought to the representation, because they have to decide to move a particular piece to a particular destination, and cannot (as in the exploratory version) simply click on various objects to see what the response of the system will be. We are currently designing experiments to see if the extra cognitive effort required by the constructive version results in increased learning, or if it is merely an additional mental overhead which is not present in the exploratory version.

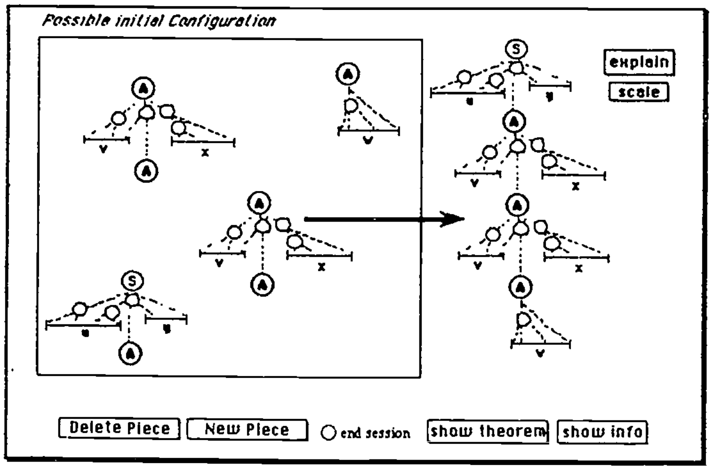


**Figure 2.** A screen from the HUGH "jigsaw" version
(inset shows possible initial state)

## Discussion

At a more general level than that of the preceding discussion, the problems associated with the design of external representations in hypermedia learning environments result, at least in part, from our being products of what has been called a "logocentric" educational culture, i.e. a culture that emphasises talk and written language to the near exclusion of any other mode of representation (Cunningham, Duffy, & Knuth, 1993). Kress and van Leeuwen (1990) suggest that our culture is not opposed to visual media *per se*, but to what they call the emerging visual literacy, as it is a threat to the dominance of verbal literacy. This dominance of verbal language has, they say, been a major cause of our inability to fully understand what is actually communicated by images. Although not addressing problems of computer system or interface design, Kress and van Leeuwen actually indicate one important source of the difficulty of hypermedia interface design:

> "Newspapers, magazines, public relations materials, advertisements ...[etc.]...involve a complex interplay of written text, images and other graphic elements...[which]...combine together into visual designs, by means of layout. The skill of producing texts of this kind...is not taught in schools. In terms of this new visual literacy, education produces illiterates" (Kress and van Leeuwen, 1990, [p2]).

The opposition to non verbal literacy takes many forms, and was recently heard in an academic discussion about diagrammatic representations when a participant was arguing fiercely that there was a level of complexity beyond which diagrams could not go, but written language could. This is unfair to diagrams on two counts. Firstly, most learners, whether subjected to verbal *or* diagrammatic information, seem to encounter a level of complexity beyond which they find it difficult to proceed. Secondly, we are not (yet) as a culture as experienced at communicating with diagrams as we are with pictures (as most diagrammatic forms we are exposed to in our education are usually, concrete, simple, and have the status of supporting illustrations). In the future we may reach an understanding of the non-verbal media that will enable us to educate much more effectively than we ever could by the use of words alone.

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