Journal of Computer Assisted Learning (1994) **10**, 81-92

Towards the architecture of an instructional multimedia database

P.W. Verhagen and R. Bestebreurtje
University of Twente, The Netherlands

Abstract The applicability of multimedia databases in education may be extended if they can serve multiple target groups, leading to affordable costs per unit for the user. In this contribution, an approach is described to build generic multimedia databases to serve that purpose. This approach is elaborated within the ODB Project ('Instructional Design of an Optical DataBase'); the term optical refers to the use of optical storage media to hold the audiovisual components. The project aims at developing a database in which a hypermedia encyclopedia is combined with instructional multimedia applications for different target groups at different educational levels. The architecture of the Optical Database will allow for switching between application types while working (for instance from tutorial instruction via the encyclopedia to a simulation and back). For instruction, the content of the database is thereby organized around so-called standard instruction routes: one route per target group. In the project, the teacher is regarded as the manager of instruction. From that perspective, the database is primarily organized as a teaching facility. Central to the research is the condition that the architecture of the Optical Database has to enable teachers to select and tailor instruction routes to their needs in a way that is perceived as logical and easy to use.

Keywords: Adaptability; Instructional database; Multimedia; Object-oriented approach; Teacher-support systems.

Context of the current ODB project

The seemingly unlimited possibilities that multimedia systems offer for presenting information in any desired format, and the interactive capabilities that stem from the built-in computer power offer, in principle, a vast range of educational applications. Traditional courseware options (e.g. Alessi & Trollip, 1985; Jonassen, 1988), types of interactive video (e.g. Bayard-White & Hoffos, 1988), instructional uses of computer simulations (e.g. De Jong, 1991; Van Schaick-Zillisen, 1990), electronic books and hypertext applications (e.g.

Correspondence: Plin W. Verhagen, Faculty of Educational Science and Technology, University of Twente, P.O. Box 217, 7500 AE Enschede, Netherlands. Email: verhagen@edte.utwente.nl

Barker & Manji, 1991; Benest, 1991; Megarry, 1988, 1991; Kommers, 1991; Kuhlen, 1991) may be combined into one system so that education can benefit from the traditional options and from the multimedia opportunities.

The current ODB Project focuses on multimedia databases for normal education. A multimedia platform is in fact a single medium (the computer) that is purported to be multiple. The term 'multimessage system' would perhaps have been more applicable, as Copeland (1991) suggests. Here, however, the now generally accepted term 'multimedia' will be used in the sense just described.

From the perspective of developing an architecture of an instructional multimedia database, the following problems need to be solved before the attractive features of the new technologies can be exploited (Bestebreurtje & Verhagen, 1990).

- The applicability of large multimedia databases depends on the retrievability of the required information to cover specific needs. The form and level for presenting that information should then match the capabilities of the user and the desired pattern of interaction (inform me, teach me, challenge me, etc. see Megarry, 1988). Design methods to accomplish this in a systematic way are yet to be developed, in particular if tuning to a variety of target audiences is required.
- There is reason to believe that, at least with respect to video, traditional audio-visual design principles will have to be altered before they can be applied (Locatis *et al.*, 1990).
- The production costs of multimedia applications are high, in particular if video components are part of it. Putting these media into practice for normal education will be dependent on a large number of copies in order to make the price per title affordable to the schools. However, in education target groups are usually relatively small. At the secondary level for instance, the number of schools of one type is, in many countries, too limited to allow for volume production.
  True (and economical) multiple use will only occur to the extent that different groups can use the same data, which has its main effect for audio and video fragments.
- The former problem is reinforced by technical constraints: although optical media such as videodisc and CD-ROM have a relatively large storage capacity, the total size of the storage capacity is limited. This sets bounds to extending a multimedia data collection for multiple use. Methodological knowledge is needed to specify the conditions for completeness of an application in such a way, that multiple use can be maximized within the limited space of the available storage medium. 'Completeness' is thereby to be understood as the capacity of the system to treat each available subject in such a way that the specified instructional objectives for each target group can be reached without a need for information other than that contained in the system. It has to be emphasized that this does not limit the use of the system to learning from the screen. System-generated study texts and worksheets, which

will be made available to the teachers, may very well be part of instructional situations.

- Education is primarily a social process between teachers and learners. In normal schools, the teacher has a central role in this process, being the manager of education. For multimedia applications to become acceptable they have to fit into this situation. This means that first of all teachers should recognize the applications as valuable tools for their teaching.
- Putting the teachers in a central position means making them partners in developing didactics and organizational patterns for the application of multimedia databases in education. In this process attention is also directed to gain experience in using a multimedia database in the school setting. This kind of experience is rare, as witnessed by the limited number of case studies that are regularly reported in the literature (e.g. Helsel, 1990).

In this paper emphasis will be placed on the requirements and the development of the architecture of the Optical DataBase and more specifically on its functional specification. This leads to the model that is presented in Fig. 1 where the main characteristics of the object-oriented database architecture that is developed for the project are summarized.

The intended end-product is an experimental database for multiple use, that is organized for educational purposes for a limited domain of knowledge and for a small but sufficient number of target groups in order to make the study feasible.

Overview of the end-product: an instructional database

The content of the Optical DataBase is based on actual curricula on cheesemaking in Dutch agricultural vocational schools with food science as a field of study. Its aim is to provide these schools with a knowledge base on cheesemaking with a degree of completeness for instructional purposes at all relevant educational levels.

Types of applications

In this educational context 'multiple applications' means uses for (1) classroom presentations; (2) individual or small group instruction (tutorial, inquiry, problem solving); (3) consulting of encyclopedic information; and (4) managing the former three. The central role of the teacher should be supported here by his or her ability to modify the database, monitor progress of learners with help of the system, and so on. The database will be organized to offer these possibilities in a coherent way, such that switching between application modes will be possible as often as desired (and when allowed, teachers will have rights that are withheld from learners). The access to the knowledge domain is done on the basis of a landscape metaphor. The user travels through the knowledge domain along instructional routes by which the knowledge landscape is opened up, thus arriving at one topic after the other. Switching between application modes means turning to a different route along which the relevant subject is treated from a different perspective. Transfer over larger distances will be made possible by building-in navigation mechanisms as used in hypertext and hypermedia applications.

Types of users

'Multiple levels of education' and 'multiple target audiences' refer to the possibilities to have applications available in different educational settings with different goals. In the Dutch system of agricultural vocational schools four levels can be distinguished: lower vocational education, middle vocational education on A or B level, and higher vocational education. The project starts serving the lower three levels of this list.

Within the schools, two types of users can be distinguished: learners and teachers. The learners will receive instruction with the database in the way determined by the teacher, either by teacher led classroom presentations or by interacting directly with the database (individually or in small groups). From the perspective of the teachers, the Optical DataBase will primarily be seen as a tool for their teaching, which offers facilities to tune its appearance to local needs and supports classroom presentations and the organization and management of individual and small-group assignments.

A third type of users is formed by the designers of the database and by those who will be responsible for the maintenance of the database when it has been developed ready for use. These users will need specific, dedicated support by the system to be able to develop and modify the database to comply with wishes that emerge from the cooperation with teachers and with domain experts from outside the schools.

All types of users will use a selection of all information that is available in the database. The designer and the teachers are able to (re-) construct and to modify the selection. The software should support needs of all types of users of the database.

Accessibility: standard instruction routes

A central aspect of supporting the teachers is ease of use of the product from their perspective. Teacher load for the use of the Optical DataBase should be minimized, both with respect to preparation of lessons and other study assignments and with respect to managing its actual use. As one measure to accomplish this, the database will be organized around *standard instruction routes*. A standard instruction route is an instructional route through the database that contains the standard curriculum for one of the target groups of learners. In the ODB Project it implies that the Optical DataBase will contain in the end several standard instruction routes for the different levels of vocational education about cheesemaking. A standard instruction route should be conceived of as default settings within the database, that allow teachers to deliver instruction to their specific target group by just switching on the route of the corresponding level. Each standard instruction route will however often not completely fit the local needs, as curricula details appear to differ from school to school. The routes will therefore be designed in such a way that they may be locally adapted.

Options for the teacher: adaptation

If the teacher is not satisfied with the standard instruction routes, these routes can be modified. This implies switching on and off parts as large as complete subjects like 'pasteurisation', 'workshop cleaning', 'laboratory procedures', or as small as specific content objects like individual sentences about subject matter details. It may also imply switching between alternative instructional patterns or between, for instance, open questions or multiple-choice questions, or changing between the multimedia combination of the output (visual-based vs. audio-based, or graphical-based vs. text-based, etc.). Using the configuration options the Optical DataBase will offer, each teacher will be able to select new default settings, thus creating a special instruction route for local use, which may be stored under a self-chosen name.

Another option for the teacher is to limit, in the browsing mode, the learners' access to the database according to the 'zone of proximal development' (Vygotsky, 1978, p.86). This implies on the one hand that learners need challenges that fit the state of their mental development, but on the other hand that learners ought to be protected from information that is to difficult to understand.

Building the optical database: basic ideas

After a preparatory phase, during which the cooperation with ten agricultural schools was established and an inventory of the curricula concerning cheesemaking was carried out, the development of the Optical DataBase is taking place in the following four phases:

- developing the database architecture to the level that the domain knowledge can be installed;
- constructing standard instruction routes;
- developing management tools, including tools to allow teachers to configure the database according to their needs;
- testing of the completed prototype in realistic educational settings.

During the first three phases, prototyping of structural components of the database is taking place on the basis of hypothesized effects of design decisions followed by formative evaluation. The iteration of tests in practice and theoretical reflection which is applied as a design method, is expected to result in the accumulation of knowledge which will help to define explicit design rules. (This engineering approach is also recognized as feasible for instructional design problems outside software engineering, Tripp & Bichelmeyer, 1990.)

Object oriented approach

The different levels and components of the Optical DataBase show a need for easy adaptability and for easy addition and removal of parts, in order to meet the requirements for multiple use as described. This led early in the project to select an object-oriented approach for building the database.

Nelson (1991) provides the following useful definitions of terms with respect to object-oriented software development.

- *Object.* An object is a 'self-contained set of variables which can only be manipulated by a set of methods (procedures) defined exclusively for that purpose' (Nelson, 1991, p.4)
- *Class.* A group of similar objects is called a class. 'A class variable is shared in both name and value by all instances of a class, while an instance variable is shared in name only by all instances of a class' (ibid.)
- *Method.* A method is an operation or procedure that is '. . . defined for the object' (ibid.).
- *Message.* An object is activated by a message from another object. This message activates the object by telling it to perform one of its methods.

Software objects have characteristics (see e.g. Coad & Yourdon, 1990; Jones, Li & Merrill, 1990; Nelson, 1991; Ullman, 1988) such as the following.

- *Encapsulation* of state and behaviour. The state is a *set of values* for the variables of the object; the behaviour is the *set of methods* that operates on the state of the object. The principle of encapsulation facilitates the independence of each object from its context in the database. Any object 'knows how to behave' when it is activated. This implies that an object can be copied, adapted and/or modified by a user as a single unit without the obligation to reconsider its whole context (storage formats, forms of appearance, reference lists, etc.). General patterns (methods) for processes of change and (re-) use are available as part of each object.
- *Inheritance* of characteristics. Objects that share specific states and behaviours are grouped together as a *class*. These classes are organized as subclasses and superclasses that together form a hierarchy. One class can have multiple superclasses and multiple subclasses. In this way a complex organisation is developed. Characteristics of the superclass, such as the specific methods, can be inherited by the subclasses. Also specific variables and values can be inherited.

These characteristics are exploited in the Optical DataBase. Examples of object classes are: the class of content components, the class of content entities, the class of basic interaction patterns, the class of route objects, the class of interface objects. These objects function on the different functional levels of the database which are discussed below.

Encapsulation causes the diverse database objects to be self supporting to a large extent. This helps when developing relatively small but coherent sets of objects to treat one topic within the database and which gives way to updating (extending) the database without severe software problems.

Inheritance leads to convenient transfer of object properties to subclasses, which supports productivity when building the database as well as its coherence. A basic tutorial interaction pattern may for instance act as a superclass of numerous variants of tutorial patterns that share (inherit) many of its characteristics.

Functional levels of the database architecture

Based upon the described characteristics of the end-product, the Optical DataBase will have the certain functional levels (from Verhagen, 1990). The overall architecture that was developed to incorporate these levels is represented in Fig.1.

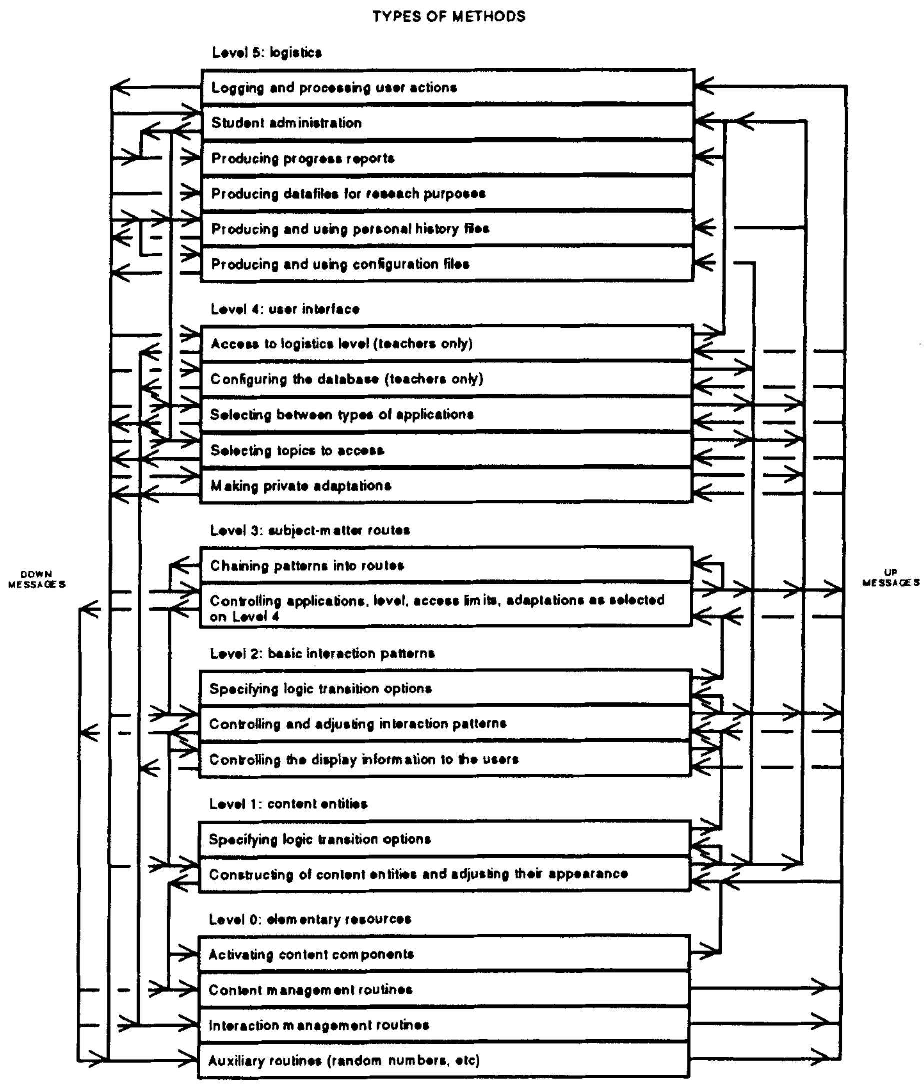

Fig. 1. Conceptual model of the architecture of the Optical DataBase.

Legend: The Optical DataBase consists of objects. The database functions by methods that are incorporated in the objects. The figure shows on what levels what kinds of methods are available. The left-hand side symbolizes the flow of messages downward. In the vertical parts of the lines at the left, messages from higher placed methods flow downward to serve as input for methods that are placed lower. At the right, the flow of messages upwards is symbolized.

Level 0: the level of Elementary Resources as stored on magnetic or optical disc

The following types are distinguished.

- Basic content components such as text strings, video stills or sequences of moving video, audio segments, graphics or animated scenes, (mathematical) software models for use in simulations. Although these units may be meaningful of their own, they are never directly accessed by the end-users of the database: the learners and teachers within the schools. Instead, they are used singly or in combinations at Level 1;
- Tools for content management, such as retrieval software to find units of content (on the Levels 0, 1, 2 and 3). Also management tools that may be used by the users of the database to modify its appearance according to local needs fall into this category;
- Tools for interaction management, such as software routines for screen lay-out, formatting of windows, formatting and presentation of text, presentation of still or moving video, audio output, input processing of keyboard strokes, mouse actions or other;
- Other — auxiliary — subroutines and supporting external programs, such as calculating routines and a random number generator.

Level 1: the level of Content Entities

At this level, combinations of basic content components from Level 0 form basic meaningful units of information. These Level 1 units will be referred to as 'content entities'. Content entities form the smallest building blocks for the information structure of the database. The content entities will be of different types, for which a theoretical instructional background is provided by Merrill (1983; 1987). A first division is into generalities (definitions, rules, principles) and instances (examples). A second one is into expository units (demonstrating, presenting), inquisitory units (questioning), and experiential units (experimenting). A content entity may be as small as to contain one single sentence, but may as well specify a relatively large narrated video segment or may be as complex as a simulation. As long as a certain content entity is always used as a self-contained unit, any size is possible in principle. So, one may say that a 'self-contained unit' follows from subject matter analysis. Choices in this respect will be made by subject matter experts.

The actual presentation of content entities to the user does not take place at Level 1. The presentation is controlled at Level 2, where the content entities are included in interactive patterns. Level 1 constitutes the knowledge base of the Optical DataBase, including knowledge-network relations (see Jones, Li, and Merrill, 1990), that act as a resource for Level 2.

Level 2: the level of basic interaction patterns

Basic interaction patterns are formed by interconnecting Level 1 units. They resemble *instructional transactions* as defined by Merrill (1991, p.123). According to Merrill, 'instructional transactions are instructional algorithms, patterns of learner interactions (usually far more complex than a single display and a single response) which have been designed to enable the learner to acquire a certain kind of knowledge or skill'. In the ODB Project, instruction is just one of the modes of use. Therefore transactions are also foreseen that specify encyclopedic paragraphs and predefined presentations.

Basic interaction patterns are invariant with respect to the subject matter that is treated in each pattern, but are highly flexible with respect to interaction strategies. It is at this point that Merrill's conception of transaction differs from basic interaction patterns. In his case, different instructional strategies require different transactions. He combines related transaction in a so-called transaction family, controlled by an enterprise transaction (Merrill, 1991, p.130). The term basic interaction pattern as used by us, in fact resembles Merrill's enterprise transaction with respect to instruction. For instruction, different strategies apply, dependent on the required performance level of the learners such as 'denoting factual knowledge', 'explaining phenomena' or 'executing procedural steps'. Which strategy will be put into operation is determined by parameters set at Level 3 or at Level 4.

Level 3: the level of subject-matter routes

At this level, all basic interaction patterns are organized into routes for use as instruction, for use as encyclopedia, and for use as presettable presentations. In fact these routes will be interwoven into one network: the overall infrastructure of the knowledge landscape. Different kinds of use will just require different itineraries through this landscape.

Level 3 constitutes the complete database as the least common multiple of all mode-specific subject-matter routes, whereby different access configurations are available to the different target groups.

Level 4: the level of the user interface

The options available at previous levels and at Level 5 are accessed through the user interface which controls all navigation including switching between the types of applications (classroom presentations; individual or small group instruction; encyclopedia; and management and maintenance of the database). The interface has different modes for the different types of users (learners, teachers and designers). The designer mode will give access to the programming environment of the database, thus offering virtually unlimited possibilities to make changes. This mode will not be discussed here further.

The learners will have access to the student administration at Level 5 to get information about their progress and about new assignments that are prepared by the teacher.

The interface will offer the possibility to choose between learner mode and teacher mode at any desired moment. The teacher mode is protected by a password. If the teacher mode is active, the interface allows the database being configured to meet local needs.

Another facility of the teacher mode is that the teacher gets access to Level 5 to define study assignments for learners or get reports about their progress.

Level 5: the logistics level

At this level there are administrative and logging facilities for organizational purposes including planning and allocating of study assignments and automatic monitoring of the progress of learners and reporting about this to the teacher. Actions of teachers to configure the database are stored in so-called configuration files. The facilities at Level 5 will also be used to collect research data.

Discussion

The architecture of the Optical DataBase as it is conceptualized within the current ODB Project, is expected to offer the flexibility and adaptability that is required to serve multiple target groups at different educational levels. Parts of the subject matter in the database will be selectable and accessible from the perspective of different types of applications (instruction, presentation, encyclopedia), dependent on the intentions and the abilities of the users. A key element is that the project aims at a multitude of interactive patterns that may be combined into varying didactic experiences. The limitations of frame-based CAI, as mentioned by Merrill (1991, p.123), are clearly avoided. Merrill overcomes these limitations by developing an instructional design system on the basis of so-called transaction shells that offers a wide variety of options to instructional designers and subject matter experts to build interaction-rich instructional systems. An important difference between Merrill's work and the current ODB Project is that Merrill aims at supporting designers who build instructional systems as end products, while the ODB project aims at building a more or less complete system that offers the teacher the ongoing possibility to configure the Optical DataBase according to local needs. The role of the teacher in this process is that of the manager of instruction, as was taken as a starting point at the beginning of this paper. It means that the teacher will be involved with selecting and adapting subject matter and with organizing the use of the Optical DataBase in the local setting.

This role of the teachers should not be confused with that of the developers of the database. The programming of the database, the tools for the teachers included, as well as filling the database is the task of the developers. The teachers are the users of their product. (Both, teachers and developers, should not try to do each others' jobs (see also Verhagen (1988) for a discussion of proper contributions of different kinds of expertise). If the developers do their work properly, the teachers should not be bothered with technical problems but instead perceive the system as a logically controllable teaching tool. To accomplish this, it is essential that the designers cooperate closely with the teachers. This notion is an important factor to help proper implementation of new technologies in schools. Collis (1991) for instance emphasizes that still too often developers design lovely systems that no target group seems to want. Close cooperation with the schools is one of the basic approaches of the ODB Project that should help to make the project a success. It is expected that the object-oriented structure leaves room for extensions that emerge from this cooperation.

To conclude a word about future developments. Networked environments seem to be an increasing trend, that will eventually lead to distributed systems that allow on-line cooperation between individuals as well as institutions using all-digital multimedia data, possibly resulting in Electronic Study Book Platforms of the types suggested by De Diana (1991). The Optical DataBase may benefit from developments of this kind as it offers the possibility to extend its architecture to connect schools and teachers for information exchange and cooperative work which would reinforce the multiple usability. But also remote maintenance would become possible, and this could lead to continuous refinement and up-dating of the subject matter in the database. For the time being, the project is confined to attempts to understand how a multimedia database should be structured to function for multiple target groups on multiple levels, with a working prototype of the database as the tentative end-product.

Acknowledgements

The authors want to express their appreciation to A. Rhemrev and W.J. Zwart, who gave valuable comments on earlier versions of this paper.

References

Alessi, S.M. & Trollip, S.R. (1985) *Computer Based Instruction: Methods and Development*. Prentice Hall, Englewood Cliffs, NJ.

Barker, P.G. & Manji, K.A. (1991) Designing Electronic Books. *Educational & Training Technology International*, **28**, 4, 273-280.

Bayard-White, C. & Hoffos, S. (1988) *Interactive Video: Introduction and Handbook*. The National Interactive Video Centre, London.

Benest, I.D. (1991) An alternative approach to Hypertext. *Educational & Training Technology International*, **28**, 4, 341-346.

Bestebreurtje, R. & Verhagen, P.W. (1990) Didactische Vormgeving van Interactieve Video als Audiovisuele Databank: Eerste Tussenrapportage [*Instructional design of Interactive Video as an Audio-visual Database: first progress report*]. University of Twente, Enschede.

Coad, P. & Yourdon, E. (1990) *Object-oriented Analysis*. Prentice-Hall, Englewood Cliffs, NJ.

Collis, B.A. (1991) The Evaluation of Electronic Books. *Educational & Training Technology International*, **28**, 4, 355-363.

Copeland, P. (1991) The Multimedia Mix. *Educational & Training Technology International*, **28**, 2, 154-163.

De Diana, I.P.F. (1991) Electronic Study Book Platforms. *Educational & Training Technology International*, **28**, 4, 347-354.

De Jong, T. (1991) Learning and instruction with computer simulations. *Education & Computing*, **6**, 217-229.

Helsel, S.K. (1990) *Interactive Optical Technologies in Education and Training: Markets and Trends*. Meckler, Westport, CT.

Jonassen, D.H. (ed.) (1988) *Instructional Designs for Microcomputer Courseware*. Lawrence Erlbaum, Hillsdale, NJ.

Jones, M.K., Li, Z. & Merrill, M.D. (1990) Domain Knowledge Representation for Instructional Analysis. *Educational Technology*, **30**, 10, 7-32.

Kommers, P.A.M. (1991) *Hypertext and the Acquisition of Knowledge*. Doctoral dissertation. University of Twente, Enschede.

Kuhlen, R. (1991) *Hypertext, ein nicht-lineares Medium zwischen Buch und Wissensbank*. Springer, Berlin.

Locatis, C., Charuhas, J. & Banvard, R. (1990) Hypervideo. *Educational Technology, Research & Development*, **38**, 2, 41-49.

Megarry, J. (1988) Hypertext and compact discs: the challenge of multimedia learning. *British Journal of Educational Technology*, **19**, 3, 172-183.

Megarry, J. (1991) 'Europe in the Round': Principles and Practice of Screen Design. *Educational & Training Technology International*, **28**, 4, 306-315.

Merrill, M.D. (1991) An Introduction to Instructional Transaction Theory. In *Proceedings of the 33rd Annual International Conference of the Association for the Development of Computer-Based Instructional Systems*. ADCIS International, Columbus, OH.

Merrill, M.D. (1987) The new Component Design Theory: instructional design for courseware authoring. *Instructional Science*, **16**, 19-34.

Merrill, M.D. (1983) Component Display Theory. In *Instructional-design theories and models: An overview of their current status* (ed. C.M. Reigeluth) pp. 279-323. Lawrence Erlbaum, Hillsdale, NJ.

Nelson, M.L. (1991) An Object-Oriented Tower of Babel. *OOPS Messenger*, **2**, 3, 3-11.

Tripp, S.D. & Bichelmeyer, B. (1990) Rapid Prototyping: An Alternative Instructional Design Strategy. *Educational Technology, Research & Development*, **38**, 1, 31-44.

Ullman, J.D. (1988) *Principles of Database and knowledge-base systems: Volume 1*. Computer Science Press, Rockville, MD.

Van Schaick-Zillisen, P.G. (1990) *Methods and techniques for the design of educational computer simulation programs and their validation by means of empirical research*. Unpublished doctoral dissertation. University of Twente, Enschede.

Verhagen, P.W. (1990) Structuur van de gegevensbank [*Structure of the database*]. (Internal report) University of Twente, Enschede.

Verhagen, P.W. (1988) Interactive Learning with New Technologies; when will it be successful? In *Interactive Learning and the New Technologies* (ed. C. Harris) pp. 70-86. Swets & Zeitlinger, Lisse.

Vygotsky, L.S. (1978) *Mind in Society*. The development of Higher Psychological Processes. Harvard University Press, London.