Woolf, B. P. and Hall, W., Multimedia Pedagogues: Interactive Systems for Teaching and Learning," IEEE *Computer,* Special Issue on Multimedia,Vol. 28 (5): 74-80. 1995.

Multimedia Pedagogues: Interactive Multimedia Systems for Teaching and Learning

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Multimedia for Teaching and Learning

Audio-visual material can provide useful aids for learning when integrated into computer-based teaching systems. However, a teaching system is only useful if the learner remains active and motivated. It is well-known that page turning or browsing does not ensure effective learning. To learn, students must *want* to learn and must be involved and active. They must be challenged to reason about the material presented. Flashy graphics and simulations are not enough; the experience must be authentic and relevant to the learner's life [Schank, 1994].

Active learning multimedia environments have been called for by other authors [Stevens, 1989; Schank, 1994]. We continue this theme and assert that multimedia, when coupled with other improvements in educational software design, can support effective and quality instruction. We propose a model for instruction which moves beyond the ‘Tyranny of the Button’ [Hall, 1994] and includes use of intelligent simulation, dynamic links (on-line generation of links based on a student’s behavior), and multimedia composition and creation. We discuss technological barriers which prevent the widespread development of effective systems along with ways in which these barriers can be broken down. Finally we suggest that truly interactive systems can evolve into multimedia pedagogues and can facilitate a shift in teaching and learning.

Background

In recent years, the term multimedia has evolved to describe the storage and display of audio-visual material as well as text and graphics in computer systems. Teachers have been using 'multiple media' presentations to enhance the learning experience of their students, such as slide shows, television broadcasts and videos, for as long as the technology has been available. As far back as the 1960’s experts foresaw the integration of audio-visual material with computer-generated text and graphics, and the potential impact this might have on education. One of the earliest documented interactive educational videodisk projects was *The Puzzle of the Tacoma Narrows Bridge Collapse* [Fuller, 1985], which was recently cited as prior art in overturning Compton's patent on interactive CD-ROM based multimedia. Pioneering work was undertaken at

MIT and led to such well-known and well-documented projects as Electric Charles (an interactive video trip along the Charles River in Boston), Galatea (a video server) and Project Athena [Hodges & Sasnett, 1993]. In the UK, one of the biggest educational interactive videodisk projects was the BBC Domesday Project which was undertaken during 1985 and 1986.

Digital video technology has been under development for almost twenty years. High quality video playback is just beginning to be available on personal computers and workstations. The large storage requirements for high quality video are now easily attained from inexpensive CD-ROM drives. An early example of the educational use of digital video technology was the Palenque project co-developed by Bank Street College of Education in New York and the set of video compression algorithms that became known as digital video interactive (DVI) [Ripley, 1988]. Palenque was essentially an educational simulation based on video that enabled the user to explore the paths of an ancient Mayan site, visit the rain forest or the Mayans, and examine maps of the area or glyph writing.

QuickTime™, digital video software for the Apple Macintosh, was one of the major driving forces behind the multimedia revolution. QuickTime™ videos can be cut and pasted into any Macintosh application. This development forced other vendors to deliver video on desktop machines without the need for special-purpose hardware. The availability of sound and moving video on desktop computers has brought about a revolution in the way information is perceived.

The technology has moved on. We now have international standards for still and moving picture compression (JPEG and MPEG respectively) and a firm basis on which to develop educational software; but we have a long way to go before multimedia systems become an effective part of the teaching and learning culture.

Case Studies

A variety of technologies are being used to achieve rich interactivity with students. This section provides several examples.

Multimedia Simulations. Simulation places multimedia in a project-based context and engages learners in situations where they can solve relevant problems. Simulations can take many forms within two main categories: those based on scenarios and those based on knowledge.

Scenario-based multimedia simulations can use video, graphics, sound, or voice to engage the user in typical situations. Excellent examples include systems to teach cardiopulmonary resuscitation, anesthesiology, or strategies for combating trauma (see, e.g., [Henderson, 1986]). However, many of these simulations provide only a few paths through a problem, no knowledge of the problem beyond those set points, and no ability to adapt the presentation to perceived user needs or individual knowledge. In other words, these simulations have no domain knowledge about the topics they present and cannot respond to student questions or explain the information beyond the presentations.

On the other hand, knowledge-based simulations contain a model of the situation and may use a planner, plan recognizer, or user model to make assumptions about the situation and the user's state of knowledge and learning needs. These simulations require complex representations and sophisticated control structures in order to be responsive and flexible to the user.

Scenario-based simulations often classify student actions as correct or incorrect, and provide little advice. However, knowledge-based systems can *respond to* idiosyncratic student activity, -- for example, suggesting that the student's action is out of order or too late, compared to an expert's action. Dynamic assessment, or on-line calculations and reasoning about user actions, can provide real-time comparisons between student and expert actions, in the context of the simulation. Because the system's recommendations reflect the current context, they are relevant and robust. Knowledge-based systems can reason about tutorial goals and identify the ones toward which the simulation should be directed.

The Cardiac Tutor. Chris Eliot, at the University of Massachusetts Computer Science Department, has built a knowledge-based simulation for teaching about cardiac resuscitation, based on extensive domain knowledge about cardiac resuscitation procedures [Eliot & Woolf, 1994]. Knowledge was encoded into the system through an iterative process involving extensive expert inputs. A formative system evaluation (measured by physician-administered final exams) with two classes of fourth-year medical students suggested that working with the Cardiac Tutor was equivalent to working one-to-one with an Emergency Room physician.

The tutor presents a graphical view of an emergency room patient. The goal is clear: save the patient by selecting the proper procedures on the screen. The tutor provides clues including spoken advice, emergency room sounds, and graphic indications of ECG trace, blood gases, and vital signs. The simulation proceeds in physiologically and clinically plausible sequences, accounting for all actions thus far applied. Simulation events drive the multimedia and pass information to the tutoring module. Student input is treated as simulation events (see Figure 1).

Figure 1: The Cardiac Tutor: Simulated Patient, ECG traces and Blood Labs

In addition to recording, restoring, critiquing and grading student performance, the tutor offers automated tutorial help. It customizes the problems presented to suit different previous levels of achievement, and assists the learning process dynamically. It gives positive feedback for good or improved performance, and categorizes and comments on incorrect behavior..

Early feedback from users has been very positive. In many cases, the system stimulated active student discussions and directed review of the textbook material, providing highly productive learning experiences. In addition, students reacted strongly to the tutor's very simple negative feedback by actively exploring the problem on their own. During the tutor evaluation, both doctors and students sought to understand the medical text based on the simulation. They argued over the exact procedure for cardiac life support and found that the simulation teased apart the required procedure more clearly than the text did.

Multimedia Composition and Collaboration. Producing a multimedia document requires that a student do more real scholarship and more significant research than preparing a text-based presentation. Students may be involved in very different multimedia aspects, such as:

- *creation* -- producing text, drawings, digitized pictures,
- *organization* -- enabling the reader to connect and move items, mark and classify them, and view the same item differently,
- *access* -- indexing and/or filtering items of a certain type and searching for patterns, and
- *communication* -- sharing work and ideas among people.

Literacy skills involving the creation and use of multimedia compositions may come to be regarded as essential, and several environments have been designed to enable young students to create multimedia communications working alone or together through distributed networks [Pea & Gomez, 1992].

Well-connected multimedia interfaces allow students to access several media forms for each piece of information, and to move among media presentations (text simulation, process description, or graphics) referencing a single topic. In the Live Information interface [Cornell et al., 1993], the student chooses the media within which information will be displayed, changing for instance between animation, text, and graphics. Students can share and reuse information because items are defined in terms of a shared database. In addition, all needed displayers and user procedures are themselves made available from a common place. (See Side Bar on Page EE.)

An alternative approach is used by the Microcosm system [Hall & Davis, 1994]. Microcosm provides a hypermedia service that supports both explicit and implicit linking. Explicit, or authored links, are maintained in link databases separately from the documents to which they apply. Any number of link databases can be operative at any one time so that users can maintain private sets of links while having access to other sets of links such as those authored by teachers or other students. This allows the student to view the data in different ways. Explicit links define relationships between different multimedia objects. Implicit links are created at run-time by some dynamic process such as a database query, a text-retrieval search, a similarity matching algorithm or an intelligent rule-base. The sharing of common sets of resources by both students and tutors is encouraged to create economies of scale and the potential for collaborative work. Microcosm links, both explicit and implicit, are applied to objects, such as a piece of text or part of an image, rather than fixed to a particular location and can be applied to objects in any application where appropriate. Hence it is possible to access links, for example to gain tutorial help or look something up in a dictionary, when working in a standard desktop environment such as a word processor or spreadsheet thus creating a fully integrated interactive multimedia environment.

Multimedia and Explanatory Systems. Several instructional systems incorporate multimedia and explanation, i.e. they understand student questions or activities and generate real-time context-based responses. (See Side Bar on Page EE.) The Microcosm-HiDES project at the University of Southampton [Hall & Colson, 1991][1] presents feedback to students about the relevance of documents that may support or counter an argument they are presenting or an analytic task for which they are collecting multimedia. The tutor suggests additional encoded materials and supports search-through information from many different types of media, including text, graphics, video and sound archives. The student accesses multimedia documents through Microcosm in the same way, using hypermedia links and similarity matching techniques such as text retrieval and database queries. One application has been used by students in the Department of History as an integral part of their studies for the last two years.

Students present the results of their work using standard word processing packages. Using Microcosm they are able to link references in their essays to documents held in the multimedia archive. In this way students can create multimedia documents and use different media sources to support their arguments without having to copy the actual multimedia data into their work. This has two important advantages: the data may be copyright protected, and the file sizes may be extremely large. Although Microsoft's OLE (object linking and embedding) could have been used, Microcosm's search and retrieval tools provide an advantage in accessing appropriate source material. The links are maintained in separate link databases, so semi-automatic

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[1] Microcosm-HiDES is a joint project between the Departments of Electronics and Computer Science, where Microcosm has been developed, and the Department of History, who are responsible for the development of the HiDES intelligent tutoring system.

procedures can be encoded to evaluate which documents the students have considered and which they have not. Each set of sources that a student cites can be considered as formulating their view on that topic and this is easily captured from the data in the link database.

Technological Issues

Technological issues being addressed to make multimedia tools more effective and widely available include:

- Transition to knowledge-based multimedia systems which reason about the curriculum, student and situation before responding
- Transition to network-based multimedia systems rather than individually equipped workstations
- Authoring tools to support rapid development of multimedia materials.

Knowledge-based Multimedia Systems. Current multimedia instructional software has a limited ability to personalize its responses to the individual student because it frequently is designed around combinations of media and situations which are only available to the student at specific instances. Such software is laborious to build and inflexible in the face of idiosyncratic student behavior.

On the other hand, knowledge-based tutors dynamically adapt their response and presentation to instructional needs by reasoning about: 1) domain knowledge, 2) tutoring knowledge, 3) student knowledge, and 4) human-computer interaction. Evaluation of knowledge-based tutors has shown that people progress to the same level of mastery in one-third the time of conventional instructional methodology and use of these systems results in a 40% improvement over classroom instruction [Anderson, 1990; Lajoie & Lesgold, 1992]. Research has demonstrated successful teaching using these tutors in military, high-school, and college courses. Unprecedented increases in learning are possible because knowledge-based instructional systems can understand the problem being solved and the presumed learning of individual students at a fine level of detail. This fosters instruction exquisitely optimized to individual students.

However, researchers are still addressing problems that continue to plague development of knowledge-based multimedia systems. Until recently these systems were notoriously difficult to build, requiring several years for just a small and focused system. Object oriented languages, easy-to-use graphical interfaces, and emerging authoring tools provide the resources to make construction of these systems less difficult. In one case, a knowledge-based tutor was built in less time than required for building traditional instructional systems [Murray & Woolf, 1992]. Problems of knowledge representation, error diagnosis and remediation, and student modeling are being addressed both to expand the scope of knowledge-based systems and to facilitate their rapid development.

Network-Based Multimedia Systems. The proliferation of high speed networks with ‘quality of service’ guarantees will enable the delivery of instructional multimedia to virtually any desktop in the world (see “Resource Management in Networked Multimedia Systems” by K. Nahrsted and R. Steinmetz in this issue). Further research into digital video and distance learning is required to provide real-time delivery of video images, lecture material and instructional material so that remote students and teachers can dynamically interact with each other. Such technology could drive down hardware costs dramatically for distributed instructional systems. The matrix of interconnected Internet hosts known as the World Wide Web is a means to an end in this regard but not the end itself. The connections merely allow a user to easily access information from another machine; they provide no domain knowledge of the information being presented.

Instructional programs on the network might contain a minimum set of multimedia resources along with a set of routines and the required drivers to make use of a pre-defined inventory of other multimedia resources available on the network [Tropea & Rothermel, 1994]. Thus a single program could make use of a large array of resources. Systems stored on the network would hold supplementary resources in a legally and technologically accessible format. Media holdings might be remote archives (e.g., the Library of Congress) or heterogeneous networks of file servers containing terabytes of catalogued sounds and images available to any program that needs them. Still images and text might be provided on the main instructional program, while full-motion video would be supplied on the network.

Authoring Tools. Effective instruction and training requires more than simple navigation among media. Conditional branching, employing programming logic, is required to evaluate the student's response or review the current question. Authoring tools must keep track of the student's activities (e.g., see Authorware, Icon Author and CourseBuilder) and enable authors to identify screens to be repeated or mastery levels to be achieved. Few commercial authoring tools encode:

- knowledge about the domain
- inferences about the student's knowledge
- tutoring strategies for responding to the student in idiosyncratic ways.

More powerful authoring tools are being developed in research laboratories. The Department of Defense, through its Advanced Research Project Agency (ARPA) has funded a large public/private consortium[2] to commercialize a number of these tools thus reducing the time and resources required to build new instructional systems. In addition, commercial cross-platform script-based tools will provide the foundation for authoring tools which allow teachers to input domain knowledge, pedagogical strategy and multimedia through graphical interfaces. Automating the building process will support both *transfer of* expert knowledge to training systems and *feedback from* cognitive scientists about the effectiveness and specificity of tutorial systems. One cross-platform authoring language, ScriptX, developed by Kaleida Labs (a joint partnership between Apple and IBM), enables creation of multimedia objects that will run on Macs, PCs, Unix workstations and TV set-top boxes.

Efficiency of Development Effort. Development of multimedia instructional systems involves extensive costs for employing multiple expertise (e.g. content expert, programmer, instructional designer, and graphics designer) and extensive resources in terms of planning, programming, observing student behavior, debugging and making the system bullet-proof. Currently, production of this material is more an art than a science. Commercial companies and universities are beginning to develop multiple instructional systems, yet many systems still result from the work of first-time unguided design-and-build teams. In addition, the financial investment for deployment is high, including the need for fast computers, CD-ROM drives, audio capability,

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[2] Consortium members include Apple Computer, Inc., Houghton Mifflin Company, PWS Publishing Company, University of Massachusetts, Carnegie Mellon University, Stanford University Medical School, and University of Colorado.

and color displays for every student seat. Fortunately, the costs of these items continues to decrease.

Conclusion

Multimedia learning environments, or multimedia pedagogues as we might call them, must be shown to be educationally effective and to provide students the same or better quality of experience as they have with traditional teaching methods. At best such systems will enhance and improve the students' quality of learning. When they work well, they may also educate in new cutting-edge ways, allowing faculty to spend less time in lectures and more time working with individual students.

The global network will enable easy access to information. Multimedia and artificial intelligence technology should play a central role in bringing this information to new levels of realism and usefulness, enabling learners to gain access to more knowledge and to a variety of media forms.

In sum, desktop multimedia has the potential to make computer education as effective as one-to-one human tutoring yet as compelling, affordable, and widespread as television. The instructional systems described in this article provide merely the base and foundational technology for what should turn into the global multimedia infrastructure for education and training of the future. Along with a shift in teaching and learning, multimedia has the potential to realize enormous gains which thus far have only been predicted for computers in education.

Acknowledgments. Dr. Woolf acknowledges support for systems development from National Science Foundation Grant MDR 8751362, and the original work of Chris Eliot, Dan Suthers and Matt Cornell in developing these systems. In addition, Robert Rose made helpful editorial comments and Gwyn Mitchell prepared the manuscript. Dr. Hall acknowledges the following for their contributions to this paper: the Microcosm team in the Multimedia Research Laboratory at Southampton; the Director of the HiDES project, Frank Colson; the staff of the ILC at Southampton; and all the staff and students who have contributed to the ILC SCHOLAR projects, particularly Philippa Reed, Julian Bailey, Paul Riddy and Sandra Peel.

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The Explanation Planner

The Explanation Planner, developed at the University of Massachusetts, can respond to a student's questions in real-time like a private tutor [Suthers et al., 1992]. Typed student queries are parsed, using dialogue history to disambiguate referents such as "the switch" in Figure 2. The response is planned using internal representations before translation into natural language. The domain knowledge for the Explanation Planner is basic electricity and electrical networks. Though not shown in the figure, the Explanation Planner reasons about and selects appropriate text and graphics to use in response to the learner's question.

Figure 2: A Dialogue with the Explanation Planner

The dialogue occurs within a direct-manipulation interface, an example of which is shown in the second question. The student mouse-selected and dragged two phrases from the Explanation Planner's first response (shown in boldface) in addition to typing the non-bold text. Displayed information remains attached to its internal representations, and the machine accessed the referents of the boldface phrases directly. Mouse-selections are also used to update an internal focus of attention data structure by bringing the selected context into the foreground. This data structure is used to disambiguate ambiguous referents and to determine what concepts are currently under active consideration.

We use the principle that media is not just an adjunct to the program or a separable piece of data which terminates upon display [Cornell et al., 1993]. Each media display, whether graphic, text, simulation or animation, is connected to and understood by the system as a different representation of the same information or data structure being taught to the student. A central theme is the separation of concept and form, or maintenance of a distinction between information's appearance (presentation) and its conceptual message (semantics) while retaining the links between the two.

In the hypothetical example in Figure 3, a student asks "What is electricity?" The system provides an animation of electrons jumping to the door knob along with a description of the processes involved.

Figure 3: A Live-Information Interface

The student was able to see several media forms of the topic based on her own queries. In a conventional hypermedia system a student can only move between presentations that are previously identified and connected by the author. Our approach has three major advantages. First, users can choose the media within which information will be displayed, changing for instance between animation, text, and graphics. Second, users can share and reuse information because objects are defined in terms of a shared information base. Third, hypermedia capabilities, i.e., accessing links to alternative media, come naturally because references between objects are links whose semantics are specified by the underlying object.

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The Scholar Project at the University of Southampton

Figure 4: The Locomotor Course Module

Figure 4 shows sample documents from an application developed by staff in the Department of Human Morphology for the Locomotor course. Students use the material in several ways: as a resource base to supplement a practical dissection laboratory; for revision and review subsequent to the practical dissection experience; and to browse through the material, constrained by the availability of self-assessment tests, i.e., specific questions, integrated into the environment. For example if students don't follow the explanatory text or don't understand a definition, the text or definition may be cross-referenced to other forms of media such as video sequences, line diagrams or photographic images to provide further explanation.

A second example is the Properties of Materials course which is given to every first-year engineering student at Southampton by the staff of the Engineering Materials Department. By its nature, this course is highly laboratory based and therefore very expensive to run in terms of staff time. As part of the Scholar project some of the more difficult laboratory sessions are being reworked as multimedia courseware that students can access freely. Figure 5 shows a screen shot from the courseware that has been developed to replace a laboratory on Phase Diagrams, a subject that is notoriously hard to teach. This application completely replaced the laboratory sessions in 1994/95. Self-assessment material is built into the application.

Figure 5: The Phase Diagram Module

A third application has been developed by staff in the Department of Oceanography and is being used to teach sampling and observation techniques before students go on an oceanographic field study (see Figure 6).

Figure 6: Sampling and Observation Techniques in the Oceanography Module

A major tenet of the Scholar project is to provide flexible, customizable and reusable learning environments within Microcosm, along with a variety of teaching methods including simulation, guided learning and problem solving.

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Biographies

Beverly Woolf is a Senior Research Scientist and Director of the Center for Knowledge Communication at the University of Massachusetts. She has a Ph.D. in Computer Science and an Ed.D. in Education, both from the University of Massachusetts and has more than 15 years experience in educational computer science research, production of intelligent tutoring systems and development of multimedia systems. She has published over 50 articles on these subjects and has delivered keynote addresses, panels and tutorials in more than 6 foreign countries. Dr. Woolf is a Councilor on the Executive Board of the American Association of Artificial Intelligence (AAAI), an editor for *IEEE Computer,* an assistant editor for *Interactive Learning Environments,* and was co-chair of the AAAI Spring Symposium on Knowledge-based Systems for Learning and Teaching.

Wendy Hall is a professor in the Department of Electronics and Computer Science at the University of Southampton, UK. Her research interests include the development of multimedia databases and applications of multimedia information systems in education, industry and commerce. Major projects include the development of the open hypermedia system, Microcosm, and the application of multimedia technology to electronic archives. She is co-Director of the Multimedia Research Group at Southampton and also co-Director of the University's Teaching and Learning Technology Project and the Digital Libraries Research Centre. Professor Hall received a B.Sc in Mathematics and a PhD in Pure Mathematics from the University of Southampton and an M.Sc in Computer Science from City University. She is a Member of the British Computer Society and a Chartered Engineer.