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DEVELOPMENT OF MULTIMEDIA MATERIALS

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INTRODUCTION

Many nations are increasing their investments in education and education technology[1] to support the transformation of teaching and learning. Yet, not enough attention is given to the development and availability of instructional contentware that makes the investments in hardware economically useful and educationally meaningful. One possible reason is that equipping schools with radios, televisions, and computers and connecting them to the Internet is simple compared to developing corresponding instructional materials.

For a visual artist about to create a new work, the choice of medium is a question of supreme importance. Each medium carries within it a certain relationship to the gesture, a demand for restraint, limitations of texture, hue, value, plasticity. For the educationist, the term, "multimedia," has become much more definite. It signals high cost, a simplistic blend of visual and aural information, and low return. Today multimedia as a means of learning is equated with tightly structured content built by a commercial vendor—a developer. It is a product, not a possibility. The excitement of choice, of trial, of process is absent.

Yet, multimedia in its broadest sense is among the most effective and egalitarian of computer-based resources available. By establishing the potential for the artful interaction between learners and content—intertwining information, skills, and even the synthesizing vision that is so important to comprehension—multimedia "contentware" is effective across the wide range of circumstances. Multimedia can be designed to:

> enhance learning in different locations and in schools of diverse quality;
> present opportunities for students working at different rates and levels;
> provide (tirelessly, without holding up other students) repetition when repetition is warranted to reinforce skills and learning; and
> compensate, in the short term, for high student populations and limited numbers of trained and experienced teachers—in combination with robust teacher development initiatives and improvements in teachers' working conditions.

In dynamic fields, such as astrophysics, genetics, or political geography, updates to contentware can ensure that teachers and students encounter and have the chance to work with current and even cutting-edge knowledge. Such encounters tie learning to the most important events of our time and underscore the general idea that knowledge itself is not fixed and finalized, that there is a universe of discoveries and a library of analyses that can be available to students.

Finally, computer-based and Web-based multimedia contentware is itself dynamic, built of bits and bytes, using software development tools that combine, in some cases, the power to create with the simplicity of use. Unlike textbooks or library-based resources, contentware has the potential to engage all stakeholders in the education system—from software developers to ministry personnel to education researchers to teachers and students—in the development of multimedia learning resources.

In this chapter we present multimedia as a tapestry of possibilities—for creation, experimentation, and communication—that is woven by students, teachers, researchers, and professionals, working with different tools across the range of media. We address:

> the context for multimedia development;
> the nature and modalities of multimedia;
> the authors of multimedia resources;
> environments and tools for multimedia development; and
> ensuring quality in multimedia.

THE CONTEXT FOR MULTIMEDIA DEVELOPMENT

A decade and more ago, national efforts to introduce ICTs in education anticipated increases in efficiency,[2] without attending to the nature of learning and cognition, or to the distinction between skills mastered in abstraction and knowledge built to be used, expanded, and eventually transcended.

To build resources that enable learners to build knowledge, we must broaden our perspective beyond building skills and memorizing facts in the abstract; if these are our educational goals, technology will prove neither cost-effective nor effective in absolute terms. If our goals include enhancing analysis, synthesis, communication, and the grasping of interrelationships in the ways in which we represent our world, we will find that technology supports and empowers all of our efforts along these lines.

The use of multimedia as engines of learning is conditioned by several dynamic contexts, including our

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evolving understanding of cognitive factors with direct bearing on learning and changes in school environment ranging from infrastructure to resources to teacher development.

The Cognitive Context

The emergence of technology as a change factor in education coincides with the sweeping influence of cognitive science and brain studies as a factor in the transformation of teaching and learning.[3] The influence of both of these forces has increased with the recognition of globalization, the concomitant demonstrations of the value of innovation, [4] and the prevalence of strong "knowledge-work" sectors.[5]

The Committee on Developments in the Science of Learning of the National Research Council[6] identified five themes that changed the conceptions of learning: memory and structure of knowledge; analysis of problem solving and reasoning; early foundations; meta-cognitive processes and self-regulatory capabilities; and cultural experience and community participation.

Beyond thinking skills, thinking dispositions are important—students must have sensibility to know when and how to apply their skills. Development of such competencies can be fostered by the creation of a culture of thinking in the classroom.[7] In this way students are able to develop successful strategies to transfer their learning to other situations.[8]

From these concepts about learning, and more recently from discussion of the skill sets needed in the "global, knowledge economy,"[9] new pedagogical rubrics have emerged that include cooperative learning, collaborative learning, active learning, project-based learning, problem-based learning, situated learning[10] and, most recently, "learning by doing." These approaches all aim at a transfer of emphasis away from rote-based methods and assessment, and the teacher as the "producer" of knowledge. Instead, they emphasize the roles that analysis, synthesis, and other higher-order cognitive skills play in learning, with particular focus on learners building their own knowledge.

Expanding our view of multimedia must also take into account multimedia examination formats.[11] Students and faculty feel that incorporation of rich media in assessment can provide additional support for learning and teaching.[12] Advances in technology, cognitive science, and measurement also show the need to reinvent large-scale assessment,[13] and this process of reinvention may stand to benefit from incorporation of multimedia.

Dynamic stimuli, such as audio, video, and animation, may make performing such tasks as problem solving more relevant to student experience.[14] To accomplish this objective, multimedia development must consider cognitive complexity, sensitivity to instruction, meaningfulness, reliability, fairness, and linguistic appropriateness.[15] Multimedia material produced for teaching and learning must be produced for assessment as well, with compatible goals, similar depth, and equal quality.

The Instructional Context

When developing educational multimedia resources, it is important to take into account objectives at the level of the individual learner, the school, and the state. Each has different characteristics, expectations, and needs, and the means to fulfill them are all interrelated. For this reason, development of learning resources is linked, strategically, with processes of educational reform and the transformation of teaching and learning. Thus, we suggest four points of focus for planning the development of multimedia educational material[16]:

Learner-Centered

> What kind of approaches and materials would be flexible enough to consider students' previous knowledge, cultural practices, and beliefs while connecting them to academic tasks?

> How can the processes of teaching and learning benefit from each student's special interests and strengths?

Project-based learning activities[17] are just one way to achieve these goals. Technology also may enable us to support these goals through a combination of preauthoring (i.e., design) tools, classroom work, portfolio-organization systems, publication systems, and collaboration tools. In such an environment, the most useful multimedia material might be small bits and pieces of software that are plugable and insertable in student's pages and projects (applets[18], Flash and Shockwave files, video clips), perhaps allowing user customizations. Examples of this combination of a tool-based learning environment and preexisting content can be found in "microworlds," often written in Java, such as *Proyecto Descartes* (*http://www.descartes.es*). In this environment, students are motivated not only by the drive for visual quality in their work, but by the opportunity to use and discuss material that they, working independently in the classroom-based learning environment, would be unable to produce on their own.

Knowledge-Centered

> How can we design curricula to promote understanding instead of the acquisition of disconnected sets of facts and skills?

> How can we develop in students the ability to think and solve problems by accessing appropriate knowledge?

Multimedia may help in making accessible themes that would be very hard to understand or to connect to reality—as demonstrated by the site, Physics 2000 (*http://www.colorado.edu/physics/2000*). It also can help in enabling learners to reframe knowledge. They may use conceptual maps linked to Web pages[19] that highlight different aspects of a content domain: how knowledge is acquired by experts; how problems are solved; what language is used in that domain; the current pathways of deepening knowledge; and the different possibilities of presentation for different publics of different ages.

Multimedia also can broaden the scope of school learning environments by enabling experiments that otherwise would be too dangerous, too expensive, or take too long. (There are already some excellent CD-ROMs available in this niche.) And visualization and modeling tools give students the opportunity to enter into much more complex knowledge-contexts (so many of which are now necessary in our world than ever before), while continuing to build their comprehension of the core knowledge of those domains.

Assessment-Centered

> How can we provide opportunities for students to revise and improve the quality of their thinking and understanding?

> Technology can help facilitate self-assessment and other meta-cognitive activities in students, in part by giving frequent feedback. Collaborative tools and communication tools may promote reflection and learning as a social activity, enhancing the potential for conceptual change.

Interactive multimedia can play a crucial role in helping students overcome misconceptions in other ways as well. Students can be enabled to develop their hypotheses as far as possible, aided by the capabilities of well-planned multimedia.[20] At that extreme point of development, visual feedback can intervene, providing alternatives or deconstructing their beliefs. It is possible to produce simulations and animations that feature embedded "expert-systems examples," demonstrating how experts have addressed the same problems or arrived at true conclusions, only after students tried the simulations on their own.

Community-Centered

> To what extent are students aware of the differences in learning in school and in their social environment? Do they identify the building blocks of knowledge, and what knowledge they already have is applicable to real-world problems?

> How can students become aware of their role in a globalizing world and understand the importance of formal education in that world?

Technology can play a crucial role in connecting schools to professionals in their communities and around the world, and by allowing the school to develop ideas and positions and make them public. What types of multimedia material support more community-centered environments? People need to see and reflect on real and very often dramatic situations. Discussions can be sparked by showing videos. It may be useful to begin with small problem sets, in which only the most relevant variables are shown; then other variables can be inserted step by step. All of these features can be implemented in well-planned simulations.

Many students are motivated to include high-quality material in their projects and pages. With access to appropriate databases of educational and multimedia resources they can search, modify, and combine such material to use in their presentations and explanations.

Clearly, there are no boundaries among these four focal areas. When we construct an assessment-centered learning environment, we create elements of a learner-centered environment. When we build a community-centered environment, we satisfy our criteria for a knowledge-centered environment. Well-designed systems combine characteristics of all four.[21] One way to ensure the interweaving of characteristics of all such environments is to ask what resources would be required for "hands-on, minds-on, and reality-on" learning activities (*IVEN project design—http://www.rived.org*).

THE NATURE AND MODALITIES OF MULTIMEDIA

Modes and Instruments

Content can be presented to learners using tools ranging from books and lectures to the Internet or even handheld computers. Each different instrument—whether a book or a handheld—communicates its content in one or more modes. A book, for example, readily accommodates text, of course, plus images that can range from line drawings to schematics to maps to photographs.

These modalities and instruments offer different "affordances" (or features that facilitate a specific type of interaction). Text, as a mode for content presentation, can present complex information, although it requires literacy, analytical, and mnemonic skills. As an instrument for text-based content presentation, books are portable and easy to read, guide sequential reading, and do not require electricity (although they do require light of some sort). They offer a balance between their ability to present large quantities of content—through both text and images—and the reader's ability to build an overview of the entire body of content—based on indexes, chapter headings, and other explicit structuring—to discover the most relevant material. A Web page, which also presents information via text and images, is easier to modify and can be linked to many other pages to provide different pathways through the text.

Of course, each instrument has its limitations as well: books are difficult to modify, and many learners find it difficult to break out of their linear pathways, and Web pages are tiring to read, require electricity and connectivity, and may divert readers far from their target objectives.

Each modality and instrument offers specific affordances in combination with specific limitations. In addition, factors such as design, construction, development, and support vary among specific resources of a given type. In addition, external factors, such as a region's technical infrastructure, its climate, overall education system, and even the health and nutrition of individual learners, will determine the degree to which a resource's affordances are realized and its limitations minimized.

Current major modalities for content presentation are text, images, audio, video, and simulations. (Simulation, as used here, includes animations that present specific content, such as Earth's travel through space, and interactive simulations that offer the learner the opportunity to change variables and observe results, as might be used to present angular momentum.) Each of these modalities can be presented via many instruments. Table 7.1 describes some of the major instruments, their affordances, and their limitations. The information presented is intended to provide an overall picture of modalities and instruments only, not to enable absolute rankings. Specific designs and implementations should be analyzed relative to the objectives they are intended to support and the environments in which they will be deployed.

Affordances can be optimized and limitations minimized for a given instrument in a specific implementation through appropriate design and development. In a multiplatform environment, for example, in which early- and late-model PCs are mixed with Macintosh computers (as in U.S. schools), interactive simulations can be written in Java to provide multiplatform interoperability. In low-bandwidth environments, requirements for plug-ins such as Flash Player can be avoided, or CD-ROMs can be used as the primary delivery instrument.

Multimedia offers the opportunity to combine instruments and modes to radically enhance the effectiveness of learning resource development efforts. Educational publishers frequently "bundle" CD-ROMs with textbooks, providing additional resources, updates, and other information. Interactive simulations are often "wrapped" with text addressed directly to learners, providing contextualizing information, and with text addressed to teachers guiding them in facilitation of classroom activities, questioning strategies, and assessment. In this sense, supporting radio broadcasts or audiocassettes with print-based workbooks comprises a multimedia combination of different instruments. In all of these combinations, not only are limitations mitigated, but the strengths of each instrument are also magnified beyond the potential of any single instrument deployed in isolation.

That above characteristic implies a fundamental goal of multimedia design—to combine instruments in ways that best address the requirements of a specific content domain, the abilities and deficits of targeted learners, and the infrastructure and systemic conditions of the prospective learning environment to achieve results beyond what is possible with individual instruments and isolated media.

The Internet and CD-ROMs, of course, have the potential to serve as platforms for the full range of modes—text, images, audio, video, and simulations. To this potential, the Internet adds the possibility of frequent updates, collaborative or participatory solutions, and near-infinite scalability. Bandwidth and platform constraints, however, continue to pose limits in most circumstances. In all instances, effective design and development processes are required to arrive at a creative, effective, and appropriate implementation that addresses specific parameters.

Technology Choices

Educational gains can be maximized for every situation when the most appropriate tools are used. It is not possible, however, to give recipes for what technology tools to use or when to use them. Each case is distinct. But we can try to identify situations where the use of certain instructional multimedia material regularly achieves success. In such cases, it is also important to keep in mind the infrastructure or pedagogical constraints that may impede effective use of such multimedia. Below, we focus on the use of video, sound, simulation, and animation, and explore considerations that affect their development.

Video

Videos motivate students by showing real-life situations, in ways that are often superior to a teacher narrating them or a text describing them. Videos can be used when

TABLE 7.1 • AFFORDANCES AND LIMITATIONS OF MODALITIES

MODE	INSTRUMENT	AFFORDANCES	LIMITATIONS
Text	Books/ magazines	> Portable > Durable > Can present complex information > Sequential structure guides learner > Little eyestrain > Moderate cost of development	> Difficult to modify (as in localization, updating, etc.) > Requires literacy plus higher-order thinking skills > Content is difficult to extract for use in other resources > High per-unit cost of publication
	Web page	> Dynamic and easily modified > Hyperlinks enable nonsequential navigation > Low cost of development and very low publishing costs > Supports interactivity (e.g., navigation, user-entered information, etc.) > Can support assessment	> Nonsequential structure may obscure critical information or cause confusion > Reading may cause fatigue > Requires PC, electricity, connection > Potential additional system requirements (e.g., Java, plug-ins)
Images	Printed photos, maps, and schematic drawing	> Concrete, specific, detailed information > Appropriate for learners with “visual intelligence” > Engaging and motivating for many learners	> Low information value relative to text > Resistant to reuse by learners > “Visual literacy” skills required for best use > High cost of reproduction
	Digital photos, maps, and schematic drawings	> Affordances similar to printed photos > Easily copied, shared, and used > Low costs for reproduction and publishing > Can be data-based or Web-served for delivery to handheld computers and other “anytime, anywhere” devices	> Limitations similar to printed photos > Require PC and electricity, possibly an Internet connection
Audio	Radio	> Can present contemporary and topical information easily > Highly accessible and potentially engaging format (no literacy skills required) > Widespread adoption in developing countries > Moderate production costs > Highly scalable > Low-cost hardware	> Information is not durable; learners can’t “review” a broadcast > Poor presentation of complex concepts > No visual component (e.g., schematics, maps, photos) > Synchronous form requires system-wide coordination (e.g., announcements, class schedules, etc.)
	Audiotape	> Wide adoption, low-cost hardware > Information persists (tape may be reviewed many times) > Moderate production and reproduction costs > Highly accessible > Supports asynchronous presentation > Sequential structure guides learner	> Poor presentation of complex concepts > Medium is not durable, especially in extreme circumstances > Studio recordings not easily modifiable or well-suited for current events

TABLE 7.1 • AFFORDANCES AND LIMITATIONS OF MODALITIES (CONTINUED)

MODE	INSTRUMENT	AFFORDANCES	LIMITATIONS
Audio (continued)	Digital audio (Web- and CD-based)	> Can present contemporary and topical information easily (Web) > Information is durable (e.g., it can be reviewed many times) > Medium is durable > Moderate production costs > Low reproduction costs; easily scaled > Easily catalogued and reused (by developers and users) > Can be indexed or catalogued to enable nonsequential access	> Requires robust PC and/or high-speed Internet connection > High storage "overhead" (in terms of hard drive capacity) > May not support presentation of complex concepts
Video	Analog	> Highly accessible and potentially engaging format (no literacy skills required) > Sequential structure guides learner > Concrete, specific, detailed information > Appropriate for learners with "visual intelligence" > Engaging and motivating for many learners > Moderate hardware costs	> High production costs; moderate reproduction costs > Complex information may be difficult to present effectively > Information may prove difficult for some learners to analyze/synthesize
	Broadcast	> Same as analog video > Can present contemporary or topical information easily	> Same as analog video; however, costs may be higher
	Digital (Web- and CD-based)	> Same as analog video > Can present contemporary or topical information easily > Easily catalogued and reused (by developers and users) > Can be indexed or catalogued to enable nonsequential access > NOTE: "moderate hardware costs" is not applicable	> Same as analog video > Requires robust PC and/or high-speed Internet connection > High storage "overhead" (in terms of hard drive capacity)
Simulations	Interactive (Web- and CD-based)	> Same as noninteractive simulations > Active-learning characteristics engage learners via several paths to reinforce concepts > Quantitative elements are supported (and reinforce conceptual learning) > Engaging and motivating for many learners > Can support assessment	> Requires robust PC and/or high-speed Internet connection > Potential additional system requirements (e.g., Java, plug-ins)

introducing a new theme to motivate and contextualize learning, after a topic has been addressed in a few class periods to aid students in applying the knowledge they acquired, or after an entire module is completed to show connections to other subjects and disciplines.

Video production is not easy. If a video is intended for widespread use or for broadcast, required resources and resulting costs mount quickly. Professionals should be involved in production of good storyboards, lighting and shooting the video, and editing and postproduction. Beta-format equipment should be used, rather than VHS, to ensure high quality. Videos produced for viewing on computers are somewhat different; resolution can be low, and it should be low for most platforms currently in schools. Such videos may be displayed to large groups via multimedia projector, or individually or in small groups on individual computer workstations. The Digital Video Disc (DVD) format brings benefits to schools in terms of storage and durability; however, most schools do not have DVD players, and care must be taken in all cases to ensure compatibility of disc formats and players.

Short videos present a whole new arena. High-compression formats such as MPEG, RealVideo, ASF, and QuickTime are suitable for delivery over the Web or by CD-ROM, and plug-in players for these formats are available as free downloads from the Internet. Short videos can be integrated into computer activities in labs or computer-equipped classrooms. They can demonstrate dramatic effects or experiments that are too costly or dangerous to be performed in schools. Production of Web- or CD-ready videos can be accomplished through relatively low-cost processes, in labs or in the open air using a camcorder, with a robust computer workstation equipped with a video card, used for editing. Specialists are not necessary.

What could limit the wide spread of video? Even short videos are stored as very large files, and Internet bandwidth (contingent on national infrastructure, Internet service provision, and school hardware) is a key factor for transmitting them. In addition, storage space and storage media can be problematic. Older computers, especially, may lack both hard drive space and processing power to run videos—and student workstations of all vintages generally lack hard drive space sufficient to store videos in any quantity. Complementary distribution of videos, via DVD, CD-ROMs, or VHS tapes, can address Internet- and computer-related problems. It can be effective to integrate time-sensitive information—such as news, student work, and so on—with large media resources, such as videos, distributed on fixed media.[22] Some multimedia authoring tools, such as Macromedia Authorware, facilitate creation of integrated online and offline media solutions.

Sound

Audio technology has been used widely with tape recorders and radio programs (see chapter 9). Some uses do not depend on the production of material, but stem, instead, from good infrastructure. For instance, students can progress rapidly in language studies if they interact with students from other places; they can hear specific and authentic dialects and languages. Advanced consumer tools that support these activities include Internet Protocol Telephony (I.P. Phone), CUseeMe, and NetMeeting. In addition, the explosive popularity of various techniques for exchanging music over the Internet has already led many students to explore the power of information exchange via Web-based and peer-to-peer collaboration.

Many students are eager to produce and publish their own sound files. It is easy to channel such motivated activity toward production of materials that also have educational value—for the creator. Again, resource considerations may pose limitations: although software is not too expensive, it is necessary to have a good sound card, a good processor, and sufficient RAM (random access memory) and storage capacity.

Maybe the most interesting materials that can be produced are those that explore sound and image at the same time. For example, we could develop an applet that explores the overlap of two sounds of equal or very close frequencies; in addition to producing the sound of both frequencies, the applet can display images of the wave superposition. Such kinds of image/sound are very effective for learning about topics that students usually find difficult. By making analogies, a teacher could guide the class through discussion and research on electrocardiography, or the differences between AM and FM transmissions. Soundry, an award-winning ThinkQuest entry, includes such an applet as well as others, like the one that shows wave fronts generated by a plane crossing the sound barrier. Other useful mixtures of sound and images might address resonance; intervals in musical tones and the analogous harmonic vibrations in nature; codification of fractals or other repeating patterns using sounds; and discussion of minimalist changes, adaptation, and rupture. And, of course, well-designed applet-based sound-and-image combinations can benefit the study of languages.

Sound files can be kept small, and the most recent Internet browsers play all common formats. For more sophisticated formats, there are free players. Simple sound cards are not expensive. So, with reasonably current hardware, technology is not a barrier to the use of audio resources.

Simulations

The most remarkable aspect of simulations is interactivity, or the opportunity for the learner to change values or conditions and see what happens. This capability motivates students to formulate and test hypotheses. Simulations represent the temporal dimension visually and experientially, making them different from images, text, sound, and video. In some cases, they can enhance experiences gained in real school science labs by allowing virtual experimentation in ideal conditions. The realism of these conditions can be increased gradually. Simulations also can enable experimentation with concepts that cannot be experimented with in actual school-based labs.

With so many possible uses for simulations, it is wise to consider each simulation's intended use before designing and developing it. Will the simulation be used to motivate students during introduction to a subject? Such cases might call for beautiful graphics or intricate outputs. Will the simulation be used in inductions, deductions, experimentation for the testing of a hypothesis, demonstration of a complex concept, or application of knowledge the learner has already gained? Each potential role has its own parameters and requirements.

Which technology should be used in developing simulations? Java and Shockwave are extremely popular with developers—so much so that recent browsers do not even require plug-ins to run code developed in these formats. And because Java is object-oriented, it facilitates the reuse of code. This characteristic has led to compilation of libraries of free applets and codes that can be downloaded over the Internet. Applications such as Macromedia Flash and Macromedia Director (with Shockwave output) are simple to use, making it quick and easy to produce simulations and integrate other media, such as sound and video.

Care must be taken, though, when the simulations become too elaborate or complex, as when they are asked to treat several curriculum topics. They can strain schools' hardware resources or prove ineffective when teachers do not receive adequate guidance or professional development. In particular, development of CD-ROM-based stand-alone suites that use interactive simulations as substitutes for school science labs tends to lead to overly complex and machine-straining products, although worthy exceptions do exist.

What kinds of delivery configurations are possible? One easy means of presenting simulations to students is to position them on "html" pages that can be served to the Internet. All computation then runs in the browser, making the simulation itself generally easy to run on any recent combination of hardware and software. However, some Java-based simulations are large and memory-intensive and cannot be run on older machines with limited processor speed and memory. It is possible, when these situations are anticipated, to run calculations in the server and transmit only data to the browser—although in these instances, bandwidth constraints and network configurations simply shift the problem to another area. Flash and Shockwave output is easy to create and often "runs light"; however, their programming languages are not as robust as Java, and these files may not run across a range of platforms.

Among the difficulties with CD-ROM-delivered simulations is cost, which may be high, based on the number of licenses required for an entire class or lab. Problems also can arise from complex or time-consuming installation procedures, complex design, and lack of technical and pedagogical support. Again, solutions to some of these challenges involve centralization of computing power and administration through client-server systems based at the lab, school, or district level.

Animations

For our purposes, animations stand in contrast with videos and simulations: they do not use real images, nor do they enable interaction with the learner. Despite these significant constraints, animations are very powerful, especially as a means of enhancing otherwise static images—whether in textbooks or on Web pages. As with other examples discussed above, animations can be used to motivate learning, demonstrate concepts, and, as tools, emphasize particular details or aspects of complex phenomena. Animations often may be the best tools for highlighting the path between modeling and reality. It is possible to create a sequence of visualizations with increasing degrees of sophistication, enabling student understanding to go far beyond crude and simple models.

Animations are created by digitizing and sequencing hand-drawn images, or directly through the use of 3-D and other software. As we have seen with other media, older computers with limited memory and slow processors have problems with animations generated by 3-D software because these are usually large and heavy.

WHO ARE THE AUTHORS OF MULTIMEDIA RESOURCES?

Over the course of the last decade, ICTs have reshaped the contours of production profoundly in all sectors. Changes in the development of materials for teaching and learning have occurred most visibly in an expanded range of available modalities—with interactive CD-ROMs, Web-based simulations, and intelligent tutors among the array of new resource types presented to educators and policy makers. However, the more profound shift in creation of educational resources centers on the changing identity of the authors of learning resources, and on changes in the relationship between authoring itself and learning.

Before the widespread adoption of ICTs in universities and schools, educational resources were generated largely by private-sector publishers or centralized government-operated organizations. Textbooks, instructional audiotapes and videotapes, and broadcasts require substantial investment in content development, and in the capital equipment required to make that content available at scale. University faculty and, at times, schoolteachers are engaged as subject-matter and pedagogical experts. But the production, marketing, sale, and delivery of resources to the education sector generally remains solidly under the control of a single organization—whether a ministry of education or a private vendor. For this reason, it is the organization—not the individual educators engaged by the organization—that retains ultimate control over the evolution of the learning resource. Whether the target client is seen to be a ministry-level decision maker, the head teacher of a state school, a teacher in the classroom, or the operator of a private school or tutoring business, it is most often the publisher developing a product who determines the scope of the resource, its requirements, and the kinds of learning opportunities it affords its users.

In some instances, centralized developers have achieved stunning successes, especially when their efforts are focused on innovation, and when such innovation is fueled by the results of research and experience.

Institutional Developers

Institutions—universities, government- or privately funded research facilities, and international agencies—may be effective developers or sponsors of multimedia resources, initially free of cost, and market considerations that may limit development in the private sector. Successful resources or approaches may be transferred later to the private sector for support and elaboration, however. In Turkey, for example, the technology research agency, Tubitek, successfully transferred its research results in education to a start-up private-sector company, Sebit (recently acquired by another Turkish firm, Vitamin), which has released a comprehensive set of interactive test-preparation tools, with efforts underway to localize these for schools in the United States and China.

Alternatively, institution-based development may provide the benefits of scaffolding projects, experiences, and innovations. The *Red enlaces* (or Enlaces Network, *www.redenlaces.cl)* of the Chilean Ministry of Education was begun in 1992 as a 100-school pilot project to assess the potential benefits of computers in education. Enlaces has evolved and expanded to keep pace with new technologies, ranging from multimedia[23] to e-mail to the Internet. Enlaces currently reaches more than 100,000 students and 10,000 teachers—including a majority of those in rural schools.[24] As a result of the program's success, Enlaces is one of two Internet resource sites, along with *Internet Educativa 2000* of the Fundación Chile, that form the backbone of the Ministry's new mega-portal, Educarchile (*www.educarchile.cl*).

Nongovernmental and nonprofit organizations have been in the forefront in linking students in innovative and effective ways. The International Education and Resource Network (iEARN, *www.iearn.org*) began in 1988 to promote project-based collaborative learning and remains among the leaders in global, Internet-based education. With a global scope that is now approaching that of iEARN, ThinkQuest (*www.thinkquest.org*) integrates knowledge-building projects with Internet design, furthering the technical skills of national and international collaborative teams.

Both the institutions and the roles they play in development of multimedia resources may vary considerably. In this section, we profile the approaches of three different initiatives.

KRDL Learning Lab

Singapore's Ministry of Education has adopted a centralized approach, sponsoring and implementing resource development by the Kent Ridge Development Laboratory (KRDL), a research lab funded by state and corporate sponsors. Private-sector development of education software in Singapore focused throughout the 1990s on resources that supplemented mastery of the K-12 (school) curriculum in preparation for the university entrance examination. Based on its consultative relationship with the Singapore Ministry of Education, the KRDL learning lab has developed, in contrast, Internet-based environments and tools that support the ministry's vision of a shift in learning from mastery of facts and skills to building knowledge. These resources include:

> *Infrastructure for Collaboration*—Support for 700 simultaneous, persistent, project-based groups of two to five students each, specifically targeting learning-based collaboration learning
> *Shared Mindtools*—Development of 10 commonly used multimedia tools for use in two- to five-student collaborative groups

- *iASSESS*—Development of a Web-based, client-server software infrastructure for providing intelligent assessment services that can be externalized to allow students to realize their strengths and weaknesses
- *HistoryCity*—Built on NetEffect technology, a networked 3-D virtual environment for children aged seven to 11, using communication, collaboration, and construction to teach children about Singapore's National Heritage

Seen together, the KRDL projects address core objectives in educational transformation outlined by the Ministry of Education, with ICTs seen as playing a crucial role. Again, the circumstances that have led to the Learning Lab's success are distinct, in that development is paired with a ministry-level vision, resource allocation is high, and the lab itself is less bound by market pressures.

RIVED (or IVEN)

In RIVED—*Red International Virtual de Educacion, http://www.rived.org* (known in English as the International Virtual Education Network, or IVEN)—several Latin American countries have contributed expertise and funding to the collaborative development of educational modules. These are intended for use in math and science education at the secondary school level, incorporating well-defined and contemporary processes into the teaching of these disciplines.

In the first phase, all participating countries—Argentina, Brazil, Colombia, Peru, and Venezuela—mapped their curricula into modules to be developed, with roughly four to eight teaching periods included in a module. Modules that were common for all countries were divided for production among them.

Modules are composed of elements (videos, animations, simulations, text, exercises, etc.) that can be combined flexibly, and are accompanied by a teacher's guide suggesting how to use the modules. The flexible use of various elements enables satisfaction of country-specific requirements, and at the same time allows reuse and linkage among disciplines and topics.

To satisfy country-specific educational priorities and the project's objectives concurrently, each country provides a production team with two or three specialists in each discipline (physics, biology, mathematics, and chemistry), one instructional designer, one Web designer, one programmer, and one information technology (IT) technician. These production teams are trained to work as multidisciplinary teams, with coordinated development processes supporting the projects' educational objectives and improving efficiency. A production manual guides the teams through the different steps of development and testing in adherence with the teaching and learning objectives established by the project.

Each module proposed for development is published in a first round for comment by other countries. In this way the acceptance and necessary adaptations are decided a priori, and new ideas for adoption or adaptation of existing material are coordinated with the development process. Production teams present a general design with specifications of content and technologies to be used (a blueprint of the module). They receive initial feedback on their modules from the teams of the other countries and from an expert panel charged with ensuring the quality of the modules. Across several reiterative stages, modules are tested for content, ease of use, and efficiency. Other testing and feedback rounds take place when production is completed. This process guarantees efficiency, sharing of expertise, and collaborative engagement.

EDUCAR

The educ.ar portal (*http://www.educ.ar*), the official education portal of the Ministry of Education of Argentina, aggregates resources for all educational levels and is representative of the many national education portals now emerging in Latin America. Educ.ar incorporates a dynamic database that is updated very efficiently. It has information on events, training information for teachers, and information on adventures and contests for students. The portal also features chat and translation.

The involvement of specialists in writing units of practice that use existing Web material, or material produced on demand by Educar's team, guarantees the development of expertise in the country. The specialists of all areas are also responsible for selecting and cataloging resources and software following a catalog system compatible with IMS (discussed later in this chapter). A multidisciplinary team of developers, discipline specialists, and instructional designers works together in the same building, increasing efficiency and sharing expertise. The work of this team is tightly coupled with teams responsible for teacher development targeting technology use nationwide.

LINKS

Project Links (*http://links.math.rpi.edu*), funded by the U.S. National Science Foundation (NSF), has as its aim the production of a library of interactive learning materials that highlight mathematics for science and engineering. The learning materials are intended for integration into existing courses and follow a predefined structure of navigation and instructional design. Each module requires one to three class periods.

Content creators in Project Links follow a process that involves completion of a module design questionnaire, detailed module storyboards, and applet storyboards. The technical manager and other authors review these materials, and a subject-matter expert reviews the module's content independently. The modules are alpha- and beta-tested in-house, then tested for usability, and finally pilot-tested in classrooms. After each step, the module is changed and improved. When this process is completed, the module is used in all participating courses. Five institutions currently participate as content creators; technical development is done at the Rensselaer Polytechnic Institute, with evaluation teams at two other universities.

Private-Sector Developers

Private-sector activities in multimedia development can also be extremely varied. Whereas private-sector activity for much of the 1990s focused on development of CD-ROM-based multimedia, with mixed results in terms of both educational and financial success, more recent activity has explored a range of models involving the Internet.

As early as 1995, a Rand Corporation study for the U.S. Department of Education linked the poor quality of CD-based education software to a fragmented and difficult-to-reach market.[25] Innovation has come, sporadically, when smaller companies have launched products that have focused on student creativity (e.g., HyperStudio), and when they have based development on a solid foundation of learning research.

Cognitive Tutor

The Cognitive Tutor math products of Carnegie Learning, Inc., exemplify an approach to multimedia development that is grounded in cognitive science, computer science, and hands-on teaching and learning. The product line addresses algebra and geometry at the secondary level in the United States. Drawing from the efforts of John R. Anderson[26] of Carnegie-Mellon University in cognitive theory and intelligent tutoring, the products:

- present math problems in the context of real-world situations and experiences;
- facilitate inductive learning;
- enable collaborative learning and peer mentoring; and
- provide in-class curriculum activities.

Centralized production, in this case by a private-sector developer, yields a learning resource that integrates a range of pedagogical attributes and spans an entire semester's curriculum. In this instance, a private-sector spin-off from academia has led to the development of a single, comprehensive, innovative resource. However, it is critically important to observe that this product has emerged within a competitive and mature education software market, one that places a premium on product differentiation. And within the decentralized U.S. education system, where purchasing decisions are made on a district-by-district basis, marketing costs are staggering, and the success of the product, and of the company that developed it, is far from certain.

Private-Sector Portal Development

In countries in which institutional or national organizations have not yet established education portals, private companies have rushed to fill that gap. In the United States, bigchalk.com has emerged as the premier aggregator of education resources and services, offering a catalog of lesson plans, productivity resources for students and teachers that include professional Web-construction tools, career and professional development resources for teachers, and a host of other resources. Because many of the lesson plans and student projects have been developed outside of the bigchalk organization, these tend to be heterogeneous, although efforts have been made to cover broad areas of the common curriculum in the United States, and to ensure that resources meet bigchalk's standards of quality.

In contrast, in Turkey, where education is highly centralized under the Ministry of National Education (MONE), portal services nonetheless have been designed and developed by a private company recently purchased by Koç Systems, the country's largest holding company. The Elma portal (*elma.net.tr*) also aggregates resources from a select group of other sites (see below). However, a combination of professional or volunteer staff, directed by a central management team, develops the bulk of the materials available on the site. In addition, Turkish educators contribute lesson plans directly to the site. Elma also offers a "homework help desk": students e-mail questions and challenges arising from homework problems, and they receive personalized responses from a staff of volunteer teachers. With the permission of the inquiring student, both questions and responses are publicly available on the site and are archived and searchable for later reference.

Challenges to Private-Sector Authorship

When private-sector development of effective CD-ROM-based educational materials has been successful, as in the case of the Cognitive Tutor, success has come despite structural factors, chiefly economic, that have tended to limit the effectiveness of resources created by centralized development. It may be instructive to review those factors historically and their effects, in part to determine their continuing effect on centralized development—for both CDs and the Internet. Chief among these factors, of course, is the persistently high cost of software development, with an average for educational CDs reported to be US$400,000 in 1994.[27]

In the United States, private-sector development of education software remained a struggling industry throughout the 1990s, despite high levels of market and venture capitalization in the technology sector and an increasing influx of technology into the schools. By the late 1990s, high development and marketing costs and low profit margins led to the consolidation of the industry in software clearinghouses, chiefly Softkey, Broderbund, and the Learning Company. By 1998, these three companies had been consolidated further through merger and acquisition, and then were acquired for US$3.6 billion by Mattel, Inc., with disastrous consequences.[28]

Pressures of this sort force private-sector developers to design education products for the broadest possible audience, including not only teachers and students in state schools and private schools, but also families, students using computers at home, and, in some cases, private test-preparation and tutoring companies. The nonschool segments of the developers' market base may prove to be larger and more easily reached by marketing efforts, and the decision to purchase may be made more easily. However, the various learning environments—school labs, after-school labs, and homes—provide learners with radically different circumstances. The one-learner/one-computer configuration implied in the design of most commercially produced education software is rarely provided in a school classroom or lab. And these designs fail to support—and may actually interfere with—the essential social aspects of learning.[29]

With low profit margins and little incentive to develop "school-only" titles, developers have little reason to assume the risks of innovation. As evidence, the Cognitive Tutor product line was recognized in 1999 by the U.S. Department of Education as one of only five of 61 available math software products as "exemplary"—after more than 10 years of multimedia development by the private sector (Eisenhower National Clearinghouse). In 1999, the Turkish Ministry of National Education rejected all bids from software developers to a tender that was part of its Basic Education Project, spanning 8,000 schools, because none of the products met their requirements.

Teacher Developers and Collaborative Efforts

Due in part to the challenges confronting private-sector developers—and in part to changes in pedagogical approaches—teachers in many countries have been seen as partners in and even drivers of development of technology-based learning resources over the past 10 years. During the early years of multimedia development in the United States, classroom teachers drove the start-up of education software companies such as Minnesota Educational Computing Corporation (MECC), Sunburst, the Learning Company, and many others. Currently, former teachers are heading companies ranging from bigchalk.com (*www.bigchalk.com*) to smaller, leading-edge businesses, including Carnegie Learning and Learning in Motion. Although its tools are solidly grounded in cognitive science, Carnegie Learning has incorporated the results of extensive field trials of its Cognitive Tutor line conducted by William Hadley, 1995's U.S. Math Teacher of the Year. Although these companies benefit from the teachers' experience and knowledge, they are constrained by market-based pressures.

New tools and new understanding of the value of the teacher's experience have combined to generate new processes to develop multimedia learning resources. Apple Computer's 1984 introduction of HyperCard gave perhaps the first promise of software learning resources developed by working teachers, and today we see teachers developing Web-based resources. Three projects initiated in the late 1990s explore teachers' potential as collaborators in resource development:

- The Educational Object Economy (EOE),
- Multimedia Educational Resource for Learning and Online Teaching (MERLOT), and
- Educational Software Objects of Tomorrow (ESCOT).

The Educational Object Economy (EOE)

The EOE emerged out of a 1993 NSF grant to the East/West Authoring Tools Group, a coalition of universities and publishers anchored by Apple Computer's Advanced Technology Group. The initial objective of the grant was to sponsor development of menu-driven "end-user" authoring tools that could reduce the high cost of multimedia CD-ROM development. However, the project met with unanticipated difficulties with the repurposing of university-built tools for commercial uses. At the same time, the emerging dominance of both the Internet and Sun's Java scripting language pointed to the decreasing importance of CD-ROM-based delivery.[30] The success of subsequent efforts to enable authoring tools to generate Java output led to a crucial realization—without coordinating mechanisms, a proliferation of authors and authoring tools leads to redundant development of the "low-hanging fruit" of software resources.[31] In 1997, the Educational Object Economy (*www.eoe.org*) launched a dynamic, database-served Website as a place where users could post interactive simulations constructed as Java applets. These small, Web-delivered simulations generally enable learners to change variables and see the results of their changes graphically and quantitatively.

Lifted by waves of interest in both Java and the Internet, and in open-source development models, the EOE now features over 2,000 Java-based simulations for education. Applets have been developed and contributed freely by teachers, students, programmers, and education researchers, with metadata that include reviews, comments, and curriculum-based activities, as well as catalog information based on an early version of the Instructional Management System (IMS) model. In roughly one-quarter of these applets, Java source code is available for modification and localization.[32]

For many reasons, the EOE has not had significant impact on education in the United States.[33] Key factors include:

> the diversity and scale of the U.S. education system;
> competition from a mature private sector; and
> limited Internet access in schools early on in the project.

In particular, as the EOE collection has grown, limitations in the catalog design have become apparent, complicating resource discovery and qualification by teachers. Because the EOE repository stores only the Uniform Resource Locator (URL) for each applet, maintaining the catalog becomes significant as addresses and posting changes occur on host servers.

However, since 1998, the EOE has begun shifting its focus to education systems in emerging economies, where multimedia development for education is beginning. In a three-week workshop outside of Delhi, India, teachers and students designed and developed interactive simulations targeting Indian science and math topics.[34] Most notably, the Turkish education portal, Elma, now mirrors the EOE repository, with Turkish-language learning activities, and several Turkish educators have now contributed Turkish-language applets to the EOE repository.

MERLOT

Based on the EOE model, and seeding its repository with EOE applets, the Center for Distributed Learning of California State University has established the MERLOT project (*http://www.merlot.org*) as a community focused exclusively on resources for higher education. The project has made several significant changes to the EOE model, including:

> collecting all learning-resource types (text, image, audio, etc.), in addition to Java applets, and
> providing dedicated programming services to faculty.

The results have included rapid compilation of more than 10,000 "learning objects" across the California State University system—many available at no cost—and increased adoption of technology by faculty. Dedicated Java programming has enabled a wider range of faculty to participate as developers, contributing interactive objects to the repository, and has led to more sophisticated Web-based support for learning in specialized fields such as health services and business education. Within the last two years, universities outside California have begun sponsoring domain-specific online communities (biology, business, physics, teacher education) as part of the MERLOT system; domain-specific search engines are planned to address issues of scale that have arisen in the MERLOT catalog as they did earlier in the EOE.

As in all community-developed repositories, quality assurance presents a significant challenge. MERLOT has introduced a system of peer review—necessary to establish the quality of the MERLOT "brand" and, in theory, to position publication in MERLOT as a tenure-track milestone.[35] Contributions to the collection are reviewed by a formal panel within the appropriate discipline and, once posted to the collection, are also open to review by the user community at large. The formal review is conducted by at least two faculty members, currently from 12 discipline-specific communities. The individual reviews are combined in a "composite review" that is posted to the MERLOT Website after sending it to the author and getting his or her feedback and permission to post. Reviewers follow a standard in their evaluation, considering separately three dimensions: quality of content, potential effectiveness as a teaching tool, and ease of use. The evaluations are expressed in written format as well as a rating using one to five stars for each dimension. The "MERLOT Review Panel" signs the reviews, and a list of the panel members is posted on MERLOT.

Additional challenges to the MERLOT model arise generally from the problematic relationship that surrounds faculty authorship, control of intellectual property, and commercialization of online higher education. Dedicated programming services increase costs in step with sophistication, with those costs often shared among several university departments. However, faculty members working with publishers arrange to bundle their MERLOT-developed online resources with textbooks.

ESCOT

In another NSF-funded initiative, the ESCOT project (with principal investigators Roy Pea, Jeremy Roschelle, and Chris DiGiano) has created a collaborative test-bed of software developers and secondary school teachers to develop small, interoperable tools to create mathematics simulations. Working with five exemplary and widely adopted math curricula, the teachers contribute both design requirements *and* learning activities. The involvement of teachers as co-designers is intended to ensure that the (again, Java-based) multimedia resources will be readily adopted in the classroom. Pairing teachers with developers for short-term development projects is intended as a model for increasing teacher participation in authoring—compared with providing the teacher with end-user authoring tools.[36]

ESCOT—like the EOE and MERLOT—addresses the high cost of multimedia development, seeking to implement one of the most promising of emerging engineering processes—integration of reusable software components. Components (also called "objects") are discrete units of software code that can be combined (or integrated) to create usable software. In ESCOT's collaboration with the Math Forum (*http://www.mathforum.org*), components are shared among 12 "integration teams" under a licensing scheme that protects attribution and intellectual property rights even after modification of a component's source code.

Benefiting from the teachers' contributions, ESCOT simulations generally are designed to be simple and easy-to-use—making them readily grasped in classrooms and computer labs. The initial ESCOT partnership with the Math Forum involved development of 48 electronic Problems of the Week (ePOWs) focused on 12 component-based simulations targeting middle school mathematics students.

In addition to the significant challenges of software reuse in educational development,[37] ESCOT faces challenges in improving its design processes and outcomes.[38] Future objectives include efforts to *increase* the role and effectiveness of teachers participating in ESCOT integration teams.[39] To address this, ESCOT researchers have proposed a very promising approach, including international participation: if funded, the TRAILS project will create ESCOT-style integration teams comprising graduate-level students in schools of education and computer science departments. The project will link participants in several countries (e.g., India) to address specific areas of the mathematics curriculum.

Student Developers

Over the past decade, many cutting-edge uses of ICTs in education have been guided by the confluence of "active learning"[40] and the emergence of new, easily mastered applications for multimedia development. Input devices, such as digital cameras and video camcorders, have dropped in price; video and sound editing can be accomplished on desktop computers; and Web pages and even Web animations can be built by anyone with access to a computer and the ability to read and comprehend a manual.

Over the course of this same period, schools and school systems have increasingly—although in many instances not systematically—incorporated active-learning pedagogies that engage students in synthesizing information derived from research across a range of sources, and in using information as the basis for alternative presentations, ranging from original plays and musicals to literary magazines to real-world experiments in physics, chemistry, and other fields. As computing power has become available in schools, computers have been deployed as the tools of resource creation.[41] In some cases, active engagement in design processes has been linked with helping learners to build "ownership" of problems, leading to knowledge creation, integration, and dissemination.[42]

In the best cases, this combination of active learning and the emergence of new, easy-to-use tools for design and development have revolved in a "virtuous circle" of multimedia resource creation. Students, themselves, now use professional or near-professional toolsets to build conceptual understanding, express ideas, and create new resources. In this section, we begin by exploring student use of the simplest tools and follow that with discussion of more sophisticated tools and their impact on development and computer use in schools.

A Scaffolded Approach to Student Authoring

To demonstrate (and build) understanding, students must organize their knowledge in rich and coherent webs.[43] Such organization has traditionally stimulated creation of concept maps. New tools now make it possible for students to perform concept-mapping activities through the creation of hypertext webs. The latter case affords students several advantages, as they use their knowledge in authentic ways, demonstrating ownership, autonomy, and effective use of symbols, and making considerations about both the audience and context. Their constructions, then, can be considered a legitimate demonstration of understanding.[44]

Concept mapping is a valuable form of learning, because formation of rich and coherent webs is not done instantaneously. Concept webs are built step by step, through working out new concepts and relationships. Very simple computer systems—supporting only a text editor and a browser—can support student use of hypertext and other media to develop their webs. Students can use familiar tools, such as a text editor, to write concept names and descriptions, and then save their work as HTML. After this step, they can insert navigation links (or hyperlinks) and open the text in an Internet browser accessing their computer's hard drive. When they are asked to return to this text, after completing other work on their project, they can then update the hyperlinks connecting both texts and start building strong and eloquent connections. Continuing this process, students link their texts to the texts of their colleagues and to their own texts produced in other disciplines; through this process, they can build their command of rich, coherent webs of understanding. In mastering this process, they also experience spontaneity in learning and the evolution of concepts.

To realize the potential in HTML-based concept mapping, file management is essential. Fortunately, network tools for schools—such as Encarta Class Server and Powerschool—have advanced to the point that such management is relatively easy. However, for schools with more limited resources, configuration of such environments without commercial tools is also feasible. For the LabVirt project of the University of São Paulo, an intranet was configured in each participating school, using Linux for the server and Windows (95 and 98) for the workstations.

When students who are rendering their work in hypertext learn how to insert images and animations, they become even more emotionally involved—they are proud of it and express their desire to advance to better tools to edit their "site." Simple visual text editors show the structure of links among arrays of pages, helping students to solidify their conceptual connections. Several projects, including LabVirt, Por Mares *(http://educom.fct.unl.pt/proj/por-mares<insert>)*, and many of the collaborative projects created through iEARN (*www.iearn.org*) point to the success of such approaches.

It should be noted that this approach goes beyond student development of PowerPoint presentations in several ways. The simplicity of HTML-based systems allows students to work comprehensively on longer-term projects without making files prohibitively large and difficult to manage. Also, the greater flexibility of hyperlinking in HTML affords students the ability to create intricate and organized networks that more accurately reflect their ideas and associations.

Harel[45] has shown that students also learn when they are engaged in design. Students who designed fraction software for other students, using the Logo computer language, learned fractions better than students who were taught fractions using conventional methods. In addition, students who used Logo to design software learned Logo better than students who received Logo programming instructions only.[46] Derivatives of Logo, including StarLogo and MegaLogo, now offer a wider range of possibilities for multimedia development by young students. Although work along this line is promising, care must be taken because students are different. While some love to develop programs, other students with different skills may prefer to frame ideas or work on refinements.[47] Collaborative teams can be structured to take advantage of these differences, but it is critical that, over the course of the curriculum, students have the opportunity to build skills in all areas.

The tools used should allow students to express themselves using symbols that are compatible with the field in question, and to test their products much like experts in a given field would. In this sense "Boxer," developed by Andrea diSessa and his team at University of California, Berkeley, is an exemplary software tool for student use.[48] One of Boxer's main characteristics is that it permits, even in very specific areas, the treatment of open problems in ways that are critical to the development of higher-order thinking skills.[49]

Students Catch Up with the Pros

The availability and ease of use of the tools mentioned above enables students to inch closer to professional developers. With these tools, students are able to develop Websites that approach the quality of professional sites (*www.thinkquest.org*), while enhancing their learning.[50] Students usually develop pages or presentations that are static or contain simple movements; however, as we mentioned, the use of Flash is changing the pattern. (There are sites that aggregate many examples and tricks [e.g., *www.flashkit.com*].)

It is not necessary for students to achieve a final product. The act of designing a Website or an animation can provide enough motivation to engage the student. And communicating the concept and parameters of a design that itself represents a specific phenomenon or principle can build fundamental and deep learning. This line is explored in the LabVirt project.[51] In this project, high school students focus on creating designs, which are then produced by university students under supervision of researchers (see Box 7.1).

Tools that might be classed as "end-user authorware," however, are making it easier than ever before for students to create and manipulate dynamic objects on the Web. Stagecast affords students the capability of programming objects by example. Students "show" to objects the behavior they want; the behavior is then recorded by the object and enacted when the object encounters identical situations. Using this simple technique, it is possible to create scripts, and even entire "worlds" of objects, interacting with one another—and the tool makes it possible to publish the results of development directly on the Internet and to access and use libraries of previously published Stagecast worlds.

Although the rudiments of programming are integral to the use of Stagecast, the tool's ease of use ensures that other

BOX 7.1 • THE *LABORATORIO DIDATICO VIRTUAL*

The *Laboratorio Didatico Virtual* (LabVirt) project of the *Universidade de São Paulo* (USP) asks secondary physics teachers to guide students, most from underprivileged neighborhoods, in project-based approaches to specific topics in the physics curriculum. These projects—in which students approach physics *inductively*—culminate in the posting of student-created designs for interactive simulations. Using LabVirt technical solutions to overcome infrastructural obstacles, students forward their designs to coordinators at USP, who facilitate both the refinement of the designs and their development by USP student programmers. At the university, a specialist analyzes the accuracy of the way physics is represented in the students' designs. (The template is informal, but the physics formulas and processes are described in a rigorous way.) The designs are then realized in the Java language, making them Web-ready and relatively interoperable across the range of hardware (486, Pentium I and II, etc.) installed in São Paulo's schools.

After development by the student programmers, a simulation is tested again for correctness. The simulation is then cataloged in the LabVirt database and sent to the school, where the student uses it. Secondary school teachers, who have the opportunity to use the animation in their classrooms, judge the educational value of a simulation.

higher-order cognitive activities may take precedence. The Stagecast site (*www.stagecast.com*) provides examples of successful student use from grade 2 to university-level computer science. Using Agentsheets (*www.agentsheets.com*), students are also able to produce elaborated animations, in this case by combining existing scripts (behaviors) visually and attaching them to graphic objects. The final products can be exported as Java to Web pages. Agentsheets "Object Exchange" aggregates the collective results of development, making object behaviors available for use by others. The educational possibilities are unimaginable, with many fine examples of Agentsheets' use, including analysis of historical information.[52] One other possibility is to use Java applets that are not closed. These provide "microworlds" that teachers and students can explore, changing parameters to generate their own applications and inserting them into Web pages. A remarkable example of this class of applets is Descartes (*http://www.cnice.mecd.es/Descartes/descartes.htm*).

ENVIRONMENTS AND TOOLS FOR MULTIMEDIA DEVELOPMENT

For professionals (and advanced students), many new developments in authoring tools have focused on increasing the dynamism and interactivity of Web-based resources. By consolidating several multimedia-authoring functions, enabling one or two developers to complete a resource, these tools not only cut the cost of authoring, but also enhance the potential of the Internet as a delivery pathway for contentware. Other new developments have addressed resource reuse, through compilation of searchable repositories, creation of combinable software components, and new protocols that attempt to ensure that resources—whether recombined components or integral wholes—are discoverable, modifiable, and interoperable. The longer-term implications of these protocols, such as Extensible Markup Language (XML), have yet to emerge. The overall trend, however, is toward increasing reliance on the Internet, more powerful "on the fly" assembly and modification of content based on a learner's profile and needs, and the ability to develop contentware for implementation across many languages, platforms, and cultures.

New Developments in Professional Authoring Tools

As mentioned above, there has been notable progress in development of professional authoring tools, allowing non-specialists to work in areas previously unavailable to them. In the past, in private-sector professional situations, a graphics designer would not engage in coding or in including his or her works in Web pages. A programmer would not incorporate a sophisticated visual design without collaborating with a graphic designer, and both might then rely on a Web designer to design a site's "architecture," decrease image sizes, and render pages across different platforms and browsers. Today, visual or menu-driven tools perform these functions. It is easy to import and format images, test pages on target browsers, and adjust fonts, color, and size for appropriate rendering. There are programming tools that use time lines and preexisting scripts (behaviors) that can be inserted into an animation simply by dragging them to the objects on the screen. Visual editors contain tools to guide the producer in connecting items in databases, which is necessary to generate dynamic pages and to manage very large sites. And—just as important—software tools that earlier produced incompatible output now enable seamless interoperability and file conversion.

If we compare the appearance of older Web pages to new ones, we can see that many of the newer pages include graphical objects that move in a synchronized way. These objects describe defined trajectories, encounter other objects, or allow interactivity via mouse clicks or numerical parameters. Even pages with these elaborate effects are not, today, the work of experts or professionals. Dynamic Hypertext Markup Language (DHTML) is a standard that allows objects to move within pages. DHTML and other technologies, coupled with the latest versions of Internet browsers, include Java machines and plug-ins such as ShockWave that make creation of sophisticated animations and simulations feasible for any technically competent Web author. Macromedia's Flash, for example, with its graphical metaphor of a temporal line and movie clips, makes it possible, without writing code, to adjust objects and actions that happen on the Web pages. Other tools, such as Photoshop, Fireworks, Dreamweaver, and GoLive, have greatly facilitated publishing and maintenance of Websites in the professional world.

The expanded possibilities of this new generation of Web tools engenders situations in which one professional may assume the roles that previously might have required two or three people working in a team. Of course, the tools themselves do not substitute for the training and knowledge that a professional graphic artist, for example, brings to bear on a problem in visual design, or that a programmer uses to create a spectacularly elegant solution in code. But creative professionals and other experts are empowered to realize more complex ideas in educational multimedia than ever before, without assistance.

Most simulations that appear in Web pages are created using Java, a language for programmers that has not been opened significantly to nonspecialists. However, while it is difficult to produce Java applets, it is not difficult to insert them into Web pages. And there are repositories (e.g., *www.javaboutique.com*) that make these resources available and facilitate their inclusion in new Web pages, by making it possible to download the necessary files and copy only two or three lines for insertion into existing HTML pages.

New Systems for Cataloging and Collaboration

The first wave of the Internet boom (1994-1997) involved the spontaneous, enthusiastic participation of many professionals. University students and faculty seized on the new medium as a way to share ideas. The idea that anyone could have access to specialized knowledge took hold, followed by the idea that anyone—even without technical skills—could publish significant new ideas and work. The concept of "net gain" was used to predict the exponential growth in value of networks of people and resources.[53] Fueled by this enthusiasm, new phrases appeared describing the tremendous change that access to information and information tools would create: An "Information Superhighway" transporting us to a "Knowledge Economy" that would usher in an "Information Age."

The freedom to access information and to publish has proven to be very positive. However, we find ourselves facing new problems: with every query, our search engines overwhelm us with too many URLs. For the educator, working within the constraints of poor infrastructure and limited time, it is extremely difficult to separate relevant material from the rest. So we have invented new phrases, such as "information overload" and even "drowning in information."

Content generators face these same difficulties and require processes to optimize production. For instance, an online course developer must combine high-quality text (written specifically for online media), images (with the trade-offs of quality and size), animations, simulations, and assessments to create an integrated, seamless experience for the learner. Weaving these different strands together is facilitated when existing material is easy to find, of course, but it is also critical for the developer to know the technical and pedagogical characteristics and the conditions of use for each component resource. With such information, developers can make decisions about acquisition, reuse, or creation. Ideally, such information, conforming to established standards, will make it possible to integrate resources built with different toolsets by different developers, or made available by different vendors.

The Emergence of Standards

Concerned with both aspects, excess of information and integration of resources, the education community has organized initiatives defining standard sets of meta-data, or data about data, to enable resources to be searched, evaluated, acquired, and combined. With minor differences among them, each meta-data definition contains:

- general aspects that are useful for everyone (e.g., the title and a general description);
- technical aspects that are useful for developers and integrators (e.g., the technology used, resource size, prerequisites); and
- pedagogical aspects useful for teachers, educators, and integrators (e.g., the target audience, estimated use time, taxonomy path).

In principle, attaching meta-data to a resource (or "learning object") ensures that the user has enough information before looking at the resource to know whether it is desirable and possible to integrate with other resources. For educational users, for example, it is critical to know if a resource is appropriate to use within a certain amount of time with students of a defined level.

Among the most influential and widely adopted meta-data standards are the Instructional Management System (IMS, *http://www.imsglobal.org/metadata/imsmdv1p2/imsmd_infov1p2.html*), the European Union's Ariadne (*http://www.ariadne-eu.org*), and the IEEE Learning Technology Standards Committee's (LTSC) Learning Object Metadata Working Group. Projects that aggregate large numbers of educational resources, such as EDUCAR (*http://www.educ.ar*), use the IMS specification to ensure that their resources are "discoverable." Leading vendors of online course management software, such as Blackboard (*http://www.blackboard.com*), also comply with IMS specifications.

Internationalization and Localization

Globalization affects every sector involved in education development; from the largest education portals (e.g., bigchalk.com) to private and even homespun efforts. Successful sites, like the Physics 2000 project—intended to introduce modern physics in high school—often are translated into several languages (*http://www.colorado.edu/physics/2000/*). Distinguished and widely recognized personal initiatives, such as the collection of simulations developed by Walter Fendt (*http://home.a-city.de/walter.fendt*), may be translated and mirrored (or duplicated on additional servers) to make them available to broader audiences. It is common to find big universities offering their online courses elsewhere, or software vendors localizing their software for other markets. Again, internationalization is most effective when it is planned in advance, and when the foundation for translation and localization is included in development frameworks and processes.

What about collaborative projects, such as the International Virtual Education Network, a joint effort of Argentina, Brazil, Colombia, Peru, and Venezuela? How does one prepare for localization into several languages and language variants at one time? In principle, everything that is text-based is easily translated. Problems occur, however, with text contained in images, animations, and simulations. In these cases, not only the translator but also the designer or programmer must participate in implementing a translation. However, newly available tools and technologies enable textual elements, such as component labels in the graphical user interface, to be stored outside the source code and retrieved dynamically. The same can be done for culturally dependent data such as dates and currencies and even images. When the simulations and animations are Java-based, the Sun specifications for internationalization can be used.[54] A very remarkable implementation of these specifications is Hwang's NTNU Virtual Physics Lab (*http://www.phy.ntnu.edu.tw/java/index.html*). This site is well known among physics teachers and contains many Java applets. Translating strings in the HTML page where a simulation is inserted is all that is necessary to reformat the simulation to run in a different language; there is no need to change the source code and then recompile the applet.

To the extent possible, private-sector and institutional developers should plan for internationalization of their products. Simple processes, such as maintaining repositories of original graphics files (with their layers intact), text files, and software components, may speed translation and localization. Such preparation also will reduce the cost of subsequent updates and modifications.

A remarkable advance is expected from the wide adoption of XML, which enables Web pages to be generated dynamically. In other words, when a page is requested, the server constructs it "on the fly" from a database of elements that can include text, graphics, video and sound, and even simulations. This new development means that one server can store and assemble elements that enable core resources—such as a video or simulation—to be embedded in Web pages in many different languages or pedagogic contexts. Popular multimedia authoring tools, such as Director and Flash, now support scripts that parse XML documents. Thus, XML and related technologies have the potential to support new architectures for internationalization of educational multimedia.

To summarize, classification and preparation of multimedia for reuse in many different national and international contexts is important in a globalized world pressed by the excess of information, high development costs, and complexity of managing information and knowledge. Without adequate planning, costs in relation to benefits for translation and cataloging of multimedia resources can be very unfavorable, limiting developers' abilities to derive revenues from international markets.

Regulating Reuse and Protecting Intellectual Property

If a content creator—student, teacher, or professional—identifies existing material that would be useful to include in his or her own resource, copyright issues must be addressed. Regardless of whether or not copyright notice is included, the content creator must contact the author or publisher of text, images, software code, or other resources and secure written permission to reproduce the resource. Exceptions are made for resources that explicitly state they are in the public domain. Also, in specific circumstances, resources may be reproduced for "fair use," whereby parts of a copyrighted work are reproduced to critique or discuss the original. (The "fair use" concept does not apply in many countries.)

Particular attention must be paid to projects that involve students as principal content creators. Even in the primary grades, students should be introduced to the need to cite the sources they are using, to teach them how to use other sources responsibly without plagiarizing or infringing on copyright. The ThinkQuest Internet Challenge competition is exemplary in this regard. Each year, teams of students under the guidance of a coach collaboratively develop Websites that address science, humanities, social science, and interdisciplinary subjects. The project has been attaining extraordinary results. ThinkQuest provides resources to assist teams working with copyright, avoiding plagiarism, and citing references (*www.thinkquest.org/resources*).

For large-scale projects that involve collaboration among many individuals and institutions, establishing procedures and policies with regard to copyright and licensing is a crucial step to ensure that all parties involved understand who will control completed resources and how available these resources will be for reproduction. When the materials are completed, licensing agreements inform end users of educational software about prohibitions against sharing, copying, or changing software code.

There are, however, licenses designed to provide incentive for further development. Open-source licensing of the Linux operating system, for example, has resulted in versions developed in more than 50 languages, a wide array of system tools and extensions, and overall improvement of the operating system as a result of contributions by thousands of programmers around the world. Linux, Apache server software, and the most recent release of the Netscape browser have been developed under the GNU General Public License (GPL, *www.opensource.org*) or a similar agreement, Mozilla. "Open source" means that the source code, which is proprietary information in the case of the Windows operating system and most other software products, is open for access and modification.

Open-source licenses allow code use, reuse, modification, and commercialization, with the condition that the modifications are made known and accessible—returned to the public domain—and that the derived work is also licensed as open-source. Under such conditions, many developers participate in the development, thereby establishing a large base of test users, decreasing costs of development, and increasing efficiency.

Many governments have identified strategic areas where software development should receive incentives, involving even private software development firms. Special attention must be paid to ensuring the widest possible dissemination of innovation, without barring firms from including the outcomes of development in commercially marketed products. In cases where the GPL might *inhibit* development by removing commercial incentives, it may be advisable to implement the Lesser General Public License (LGPL). Under the LGPL, specialized code that can be instrumental in the production of other software, such as an open library of math software, is licensed separately for use in commercial and noncommercial products. All modifications and additions to existing code must be returned to the open library, but the end product is not included in the library and can be protected under a different and a more restrictive license.

The PROTEM line of funding *(http://www.cnpq.br/areas/sociedadeinformacao/protem-cc/index.htm)* administered by the CNPq—the national agency for science and technology in Brazil—offers an example of a case in which release of software under the LGPL *could* spur increased development. The funding requirements state that three institutions, private or public, should be involved in each collaborative project, and that each project must include computer science, pedagogy, and psychology. Twenty projects have been supported to date, many of which involve the use of intelligent agents to collect individual cognitive characteristics of students navigating through course material, and then deliver personalized content and present feedback on heuristic strategies for problem solving. The intelligent agents are sophisticated artifacts derived from concepts in Artificial Intelligence. Further development could be fostered if the existing agents follow standards for specification, reuse, and integration—as in the LGPL—and if developers were able to integrate them to develop commercial and noncommercial dynamically adaptive educational products. (Such products would include software and course material that adapt automatically to personal characteristics, infrastructure, special needs, and other factors.[55])

Open-source educational software is available on the Internet, much of it in the form of Java-based simulations. However, in some instances, projects have begun in very open modes and then have found it necessary to restrict use and access to achieve sustainability or increased control over the use of resources. The ExploreScience and ExploreMath sites (*www.explorescience.com* and *www.exploremath.com*) are wonderful examples of the use of simulations to foster learning. In the early stages of these sites, visitors to them could download simulations onto their hard drives for use offline—a necessary feature in many schools with poor

Internet access or other infrastructure limitations. New resources developed for these sites, however, can only be run over a “live” Internet connection, although it is still possible to follow links to a classic version of the site that offers older resources in compressed, downloadable versions.

There are other examples in which restrictions have been applied after projects have been launched. The Links Project (*http://links.math.rpi.edu*) is an exemplar project that connects math learning to the use of math in science and engineering. The site provides examples and templates that allow participation of teams of content and technical developers, while ensuring a uniform “look and feel” for all resources. Early versions of the applets produced in this project were accessible and were excellent examples of good coding. However, the code for these resources is no longer available. This is a typical case of noncommercial use that could very well benefit from a GPL license.

Many educational portals have begun by offering free access, and then have shifted to fee-based access. Biology Labs Online (*http://www.biologylab.awlonline.com*), which contains interactive, inquiry-based biology simulations and exercises, started by offering free access to the first labs. Now, however, visitors to the site receive three days’ free access, for trial purposes, after which a subscription is required.

ENSURING QUALITY IN MULTIMEDIA

As the list of potential multimedia authors grows to include students, teachers, and academics, evaluation and quality assurance become critical. In specific circumstances, such as acquisition of commercial software products, any of the widely available evaluation frameworks will yield acceptable results, including:

> California Information Technology Clearinghouse (CITC) (*http://clearinghouse.k12.ca.us*)
> American Dental Association (ADA) Guidelines for the design of educational software (*http://www.ada.org/prof/prac/stands/index.html*)

Of these and others that are used widely, the ADA framework is surprisingly comprehensive and easily applied. Its major categories include:

- pedagogical issues (e.g., instructional methodology),
- subject matter (e.g., information accuracy),
- language and format (e.g., appropriateness, presentation),
- surface features (e.g., interface design),
- questions (e.g., assessment),
- feedback (e.g., meta-cognitive support),
- invisible functions (e.g., record keeping, security), and
- formative evaluation (e.g., testing and evaluation during development).

It is important in applying any framework of evaluation, however, to bear in mind strategic educational objectives as well as the overall context of software support for education. It is equally important to be prepared to recognize the strokes of creativity and innovation that may fall outside the range of existing frameworks, but that distinguish excellence from the norm.

However, as we broaden our understanding of authoring to include the contributions of teachers and students, the parameters of evaluation shift. When students are engaged in design-related activities, for example, our strategic goals may include maximizing participation in both creating and evaluating multimedia, in addition to factual accuracy, clarity of presentation, and effectiveness. When teachers and university faculty, taking advantage of the powerful new tools at their disposal, assume the role of designers or developers, software evaluation and quality assurance again must be approached with a degree of creativity. The effort to build participation in multimedia development throughout the educational community may require incentives—such as those provided by peer review—and safeguards of field templates, testing, and other measures.

Evaluative Methodologies

Four projects that have been introduced previously exemplify different evaluative processes:

- *LabVirt*—A university specialist analyzes students’ simulation designs to determine that physics is represented accurately; completed applets are tested; using the applet in their classroom, teachers evaluate its educational value.
- *RIVED*—Different phases of development of multimedia modules are posted and reviewed by country-based teams and an expert panel; each module is tested for implementability; the whole course is implemented and evaluated in pilot schools.
- *Project Links*—Initial designs are reviewed by a technical manager, other authors involved in the project, and a subject-matter expert; modules receive technology testing in-house, followed by usability testing and pilot implementations.
- *MERLOT*—Formal peer review, involving two or more appropriate faculty, is conducted on contributions to the repository; peer review addresses content, effectiveness, and ease of use; once posted, resources are also subject to “open review” by all users.

These evaluative processes are well-structured versions of standard practice. The Internet has given rise, additionally, to alternative evaluative mechanisms, known as "social filtering." These may find their place in education soon. On sites that include open review, individual users have emerged as "trusted guides" by virtue of their prolific and consistently valuable contributions of reviews to the user community. Open reviews also have given rise to instant polling, in which users contribute simple opinions ("thumbs up/thumbs down") or add more detailed annotations to those of users before them.[56] Closer to the cutting edge, sites now are able to monitor "interaction histories" by adding tracers of use or "footprints" to specific Web resources. This information is displayed as a guide to subsequent users.[57] On some current sites (*www.slashdot.com*), resources that receive the most traffic may, for example, become more "discoverable" in searches, increasing their visibility on the site.

Usability Testing

For professional and institutional developers working in resource-rich environments and under great pressures to succeed, evaluating materials after they are completed may be too late. Critical resources, including time and money, will have been expended. While functionality testing may ensure that the product works in its intended environment, it will fail to reveal flaws in the instructional design and perhaps in the design of the interface. Even review by panels of experts may not uncover the fact that the target audience—say, upper elementary students—finds the visual design dated, the interface too complex, and the rewards for success not motivating. The product may work flawlessly as designed, but it may fail to work with learners.

Iterative usability testing should be woven throughout product design and development, as a means of ensuring that these processes are meeting their overall goals, not only their project milestones. Testing may involve observation of users working with the product, surveys and questionnaires, even review of individual navigation histories on a given Website. Subject-matter experts, designers, and engineers may not be familiar with current practice in this arena, and may feel initially that such measures impede their progress. However, working with trained personnel, they can quickly recognize the clear and significant benefits of integrating usability testing into resource development.

CONCLUSION

Multimedia resources—considered in terms of both products and processes—have great potential to enhance education. New modalities and instruments for development and delivery have radically increased the support that these resources can give students across a wide range of learning activities. Despite the glamour of technology-rich environments, focus must remain on learners and their motivations and challenges, on the knowledge domains to be explored, and on the communities in which learning will take place. We also must keep in mind that developers, teachers, and students all have roles to play in the creation of multimedia, and one of the chief goals of policy must be to support appropriate activities by each of these groups.

Flexibility is a key property of multimedia contentware, and must be marshaled effectively in our development efforts. Despite the complexity of their interaction, the contexts for development and implementation—cognitive, instructional, and technological—can be balanced so as to advance strategic goals and plans within our education systems. Cognitive science, in particular, can guide and give shape to innovation in the development of learning environments, multimedia resources, and teaching and learning practice. Both institutional and private-sector developers can draw on advances in learning science to design innovative and effective contentware. The RIVED project provides a valuable example of collaboration among educators, developers, and policymakers to create an array of proven multimedia resources for regional delivery. RIVED, ESCOT, and others projects engage teachers in sharing their first-hand knowledge of learners, the curriculum, and classroom practice, via processes of review and field-testing. In projects such as the EOE and MERLOT, teachers and university faculty have made invaluable contributions to the growth of online repositories of multimedia resources.

We have seen also that trends in authoring tools and pedagogy support the active engagement of students as designers, as creators, and as publishers. The LabVirt project, ThinkQuest, and iEARN engage students in collaborative problem solving through design-based activities. However, students are strongly motivated by the many new media possibilities for information exchange and communication, such as MP3 files, instant messaging, and peer-to-peer networking. These and other media should be kept in mind, and integrated into ICT planning when the opportunity arises.

Authoring tools support increased ease-of-use and increased power, creating change in development teams and processes at all levels, from the professional to the student. These tools also give rise to new economies, based on reuse, shared code, and more flexible platforms. Institutional and professional developers can create resources that are compatible with the computing platforms and communications infrastructures available to their target populations. Development at all levels—by students, teachers, and professionals—can be promoted through the establishment of libraries or repositories of multimedia resources. Such repositories become focal points for active collaboration, sharing of information, and reuse of material. Appropriate protection of intellectual property and of public access must be balanced, using mechanisms that may include the LGPL or the GPL.

As always, factors outside the development processes and even outside the educational systems affect the creation of effective resources. It is vital for policy makers to influence funding, licensing, and standards for the development of educational multimedia by the private sector. Leading-edge technologies, including tools for adaptive and collaborative learning, will be introduced only with appropriate guidance and effective incentives, yet such tools are vital to realizing the promise that technology holds for personalized instruction and for the integration of higher-order thinking into all aspects of education.

ENDNOTES

[1] Gaible, E. (2001). *Distributed Development of Educational Software in Transitional Economies.* Palo Alto, CA: The Emerging Markets Forum.

[2] Jalaluddin, A. (1996). Opportunities and Strategies for Change in Education. In Ahmet, M., & Gaible, E. (eds.). *Education for All Technology Roundtable.* Berkeley: People's Computer Company.

[3] Bransford, J.D., et al. (2000). *How People Learn: Brain, Mind, Experience, and School* (Expanded Edition), National Academic Press.

[4] Atkinson, R., & Court, R. (1998). *The New Economy Index: Understanding America's Economic Transformation.* Washington: Progressive Policy Institute.

[5] Wolcott, P. (2000). *The Diffusion of the Internet in the Republic of India.* Omaha, NE: The Global Diffusion of the Internet Project.

[6] Bransford, op cit.

[7] Tishman, S., Perkins, D.N., & Jay, E. (1994). *The Thinking Classroom: Learning and Teaching in a Culture of Thinking.* Boston: Allyn and Bacon.

[8] Perkins, D.N., and Salomon, G. (n/d) The Science and Art of Transfer. Harvard Project Zero. Available at: *http://learnweb.harvard.edu/alps/thinking/docs/trancost.pdf.*

[9] DeVol, R. (1998). *America's High-Tech Economy: Growth, Development and Risks for Metropolitan Areas.* Santa Monica, CA: The Milken Institute.

[10] Roschelle, J. (1995). *What Should Collaborative Technology Be? A Perspective from Dewey and Situated Learning.* Proceedings of the Computer Science and Collaborative Learning Conference. Mahwah, NJ: Lawrence Erlbaum Associates.

[11] Nunes, C.A.A., Davis, C., Nunes, M.M.R., & Setubal, M.A. (2001). Problem Solving and Metacognition. Projects Evaluation Workshop of the Multi-Institutional Programs in Computational Science. Rio de Janeiro; Muller, P., Deusdeti, C., & Prugner, N. (eds.) (2002). Brazil: CNPq.

[12] Liu, M., Papathanasiou, E., & Hao, Y-W. (2001). Exploring the Use of Multimedia Examination Formats in Undergraduate Teaching: Results from the Field Testing. *Computers in Human Behavior,* 17: 224-248.

[13] Bennett, R.E. (2001). How the Internet Will Help Large-Scale Assessment Reinvent Itself? *Education Policy Analysis Archives,* 9 (5). Available at: *http://epaa.asu.edu.*

[14] Bennett, R.E., Goodman, M., Hessinger, J., Kahn, H., Ligget, J., Marhall, G., & Zack, J. (1999). Using Multimedia in Large-Scale Computer-Based Testing Programs. *Computers in Human Behavior,* 15: 283-294.

[15] Baker, E.L., & Mayer, R.E. (1999). Computer-Based Assessment of Problem Solving. *Computers in Human Behavior,* 15: 269-282.

[16] Bransford, op cit.

[17] Wiske, M.S. (1998) What Is Teaching for Understanding? In Wiske, E. (ed.). *Teaching for Understanding: Linking Research to Practice.* San Francisco: Jossey-Bass Publishers.

[18] An *applet* is a program written in the Java TM programming language that can be included in an HTML page, much in the same way an image is included.

[19] Herl, H.E., O'Neil Jr., H.F., Chung, G.K.W.K., & Schacter, J. (1999). Reliability and Validity of a Computer-Based Knowledge Mapping System to Measure Content Understanding. *Computers in Human Behavior,* 15: 315-333.

[20] Nunes, M., & Davis, C. (2001). New Technologies, New Ways of Learning? Presented at The Future and Challenges of Educational Assessment in the 21st Century, 27th Annual IEAE Conference. Rio de Janeiro, Brazil.

[21] Riel, M. (2000). Measuring the Impacts and Shaping the Future, White Paper, Secretary of Education, Conference on Educational Technology, Washington, DC.

[22] Samson, P., et al. (1999). Hold the Java! Science Activities via Networked Multimedia CD-ROM's. *Interactive Multimedia Electronic Journal of Computer-Enhanced Learning,* 1 (1).

[23] Hepp, P., Rehbein, L., Hinostroza, E., Laval, E., Dreves, C., & Ripoll, M. (1994). "Enlaces" A Hypermedia-Based Educational Network. Paper presented at the ACM Multimedia: The Second International Conference on Multimedia, San Francisco, CA.

[24] Hinostroza, E., Hepp, P., & Laval, E. (2000). *Enlaces: The Chilean ICT Experience in Education.* Geneva: International Telecommunications Union.

[25] Rand Corporation. (1995). The Market for Educational Software. Workshops on Critical Issues. Available at: *http://www.ed.gov/Technology/Plan/RAND/Software.html.*

[26] Anderson, J. R., Boyle, C.F., & Reiser, B.J. (1985). Intelligent Tutoring Systems. *Science,* 228: 456-467; Anderson, J. R., Boyle, C.F., Farrell, R., & Reiser, B.J. (1987). Cognitive Principles in the Design of Computer Tutors. In P. Morris (ed.), *Modelling Cognition.* New York: John Wiley & Sons?; Anderson, J. R., Corbett, A. T., Koedinger, K., & Pelletier, R. (1995). Cognitive Tutors: Lessons Learned. *The Journal of Learning Sciences,* 4: 167-207; Anderson, J.R. (1996). ACT: A Simple Theory of Complex Cognition. *American Psychologist,* 51: 355-365.

[27] Graves, J. (November, 1995). Take the Three Rs, String and Baling Wire. . . Education, CD-ROM and the Internet. *WWWiz Magazine,* 1 (3). Available at: *http://wwwiz.com/issue03/wiz_f03.html*

[28] Fisher, L. (2000). Mattel Decides to Put on Sale Software Unit Bought in May. *New York Times* (April 4).

[29] Repenning, A., Ioannidou, A., & Ambach, J. (1998). Learn to Communicate and Communicate to Learn. *Journal of Interactive Media in Education,* 98 (7).

[30] Spohrer, J., Sumner, T., & Shum, S.B., (1998). Editorial, Special Issue on Authoring Tools and the Educational Objects Economy, *Journal of Interactive Media in Education.* Available at: *http://www-jime.open.ac.uk/98/ew-editorial/ew-editorial.html.*

[31] Gaible, op. cit.

[32] Spohrer et al., op. cit.

[33] diSessa, A.A., Azevedo, F., Friedman, J., Kynigos, K., & Parnafes, O. (2001). Comparative Study of Component Software Initiatives. Berkeley: University of California. Available at: *http://www.soe.berkeley.edu/~boxer/webcomp/reports.html.*

[34] Gaible, E. & Rudolph, S. (1998). *The Jiva Java Project: Indian Teachers and Students as Software Developers.* San Jose, CA: The EOE Foundation.

[35] Feemster, R. (July/August 2000). Swap Shop: The Future of Online Learning Lies in Course Objects. And the Place to Find Them Is an Organization Called Merlot, *University Business:* 35-40, 73. Available at: *http://www.universitybusiness.com/0007/merlot.html.*

[36] Roschelle, J., Pea, R., DiGiano, C., & Kaput, J. (1999). Educational Software Components of Tomorrow. In *M/SET 99 Proceedings* [CD-ROM]. Charlottesville, VA: American Association for Computers in Education. Available at: *http://www.escot.org/docs/MSET_ESCOT.html.*

[37] Roschelle, J., DiGiano, C., Chung, M., Repenning, A., Tager, S., & Treinen, M. (2000). Reusability and Interoperability of Tools for Mathematics Learning: Lessons from the ESCOT Project. In *Proceedings of Intelligent Systems & Applications at University of Wollongong, NSW Australia.* Wetaskiwin, Alberta, Canada: ICSC Academic Press, pp. 664-669.

[38] Hand, V., & de Frondeville, T (n/d). Square Bowling: A Middle School Mathematics Activity that Explores Fractions as Scaling Ratios Using ESCOT Software Components in an Online Format. Unpublished manuscript.

[39] Barnes, D., Underwood, J., & Roschelle, R. (April 2000). Educational Software Components of Tomorrow. Presented at the American Education Research Association in New Orleans, LA.

[40] Boswell, C., & Eison, J. (1991). *Active Learning: Creating Excitement in the Classroom.* ASHE-ERIC Higher Education Report No. 1. Washington: The George Washington University School of Education and Human Development.

[41] Corcoran, K. (2000). Teachers Strive to Show What Adding Technology to Classrooms Can Mean. *San Jose Mercury News* (November 28).

[42] Arias, E., Eden, H., Fischer, G., Gorman, A., & Scharff, E. (1999). *Participation and Empowerment. Proceedings of the Conference on Computer-Supported Collaborative Learning.* Stanford, CA: Stanford University, pp. 20-32. Available at: *http://www.cs.colorado.edu/~l3d/systems/EDC/pdf/cscl99.pdf.*

[43] Mansilla, V.B., & Gardner, H. (1998) What Are the Qualities of Understanding? In Wiske, M.S. (ed.). *Teaching for Understanding: Linking Research to Practice.* San Francisco: Jossey-Bass Publishers.

[44] Wiske, op cit.

[45] Harel, I., & Papert, S. (1991). Software Design as a Learning Environment. In Harel, I., & and Papert, S. (eds.). *Constructionism.* Norwood, NJ: Ablex, pp. 41-84.

[46] Schacter, J. (2000). *The Impact of Education Technology on Student Achievement—What the Most Current Research Has to Say.* Milken Exchange of Education Technology.

[47] Spohrer et al., op cit.

[48] diSessa, A.A. (2000). *Changing Minds—Computers, Learning, and Literacy.* Cambridge: MIT Press, chapter 7.

[49] Bruer, J.T. (1999) *Schools for Thought—A Science of Learning in the Classroom,* 5th ed. Cambridge: MIT Press, pp. 272-275. MIT Press.

[50] Liu, M. (1998). A Study of Engaging High-School Students as Multimedia Designers in a Cognitive Apprenticeship-Style Learning Environment. *Computers in Human Behavior,* 14:387-415.

[51] Nunes, C.A.A. (1999). Laboratório Didático Virtual. Unpublished project proposal; Henderson, B., & Gaible, E. (1999). *A Virtual Lab in Brazil.* San Jose, CA: The EOE Foundation.

[52] Ioannidou, A., Reppening, A., & Zola, J., (1998) Posterboards or Java Applets? In Bruckman, A., Guzdial, M., Kolodner, J., & Ram, A. (eds.). *Proceedings of the International Conference on the Learning Sciences.* Atlanta, GA: Association of the Advancement of Computing in Education, pp. 152-159.

[53] Hagel, J., III, & Armstrong, A.G. 1997. *Net Gain: Expanding Markets through Virtual Communities.* Boston: Harvard Business School Publishing.

[54] O'Conner, J. (1998) Java Internationalization. Online articles of Sun Developer Connection. Available at: *http://developer.java.sun.com/developer/technicalArticles/Intl/IntlIntro/index.html.*

[55] Stevens, R., et al. (1999). Artificial Neural Network-Based Performance Assessments. *Computers in Human Behavior,* 15: 295-313.

[56] Maltz, D., & Ehrlich, K. (1995). Pointing the Way: Active Collaborative Filtering. ACM Portal on Computing Literature. Proceedings of Conference on Human Factors in Computing Systems (CHI '95). New York: Association for Computer Machinery. Available at: *http://www.acm.org/sigchi/chi95/proceedings/papers/ke_bdy.htm.*

[57] Wexelblat, A., & Maes, P. (1999). Footprints: History-Rich Tools for Information Foraging. Proceedings of Conference on Human Factors in Computing Systems (CHI'99). New York: Association for Computer Machinery, pp. 270-277. Available at: *http://www.acm.org/sigchi/chi95/proceedings/papers/ke_bdy.htm.*