Understanding Software Interoperability in a Technology-Supported System of Education

by Kurt Rowley

As technical compatibility standards have become critical in business and industrial computing, educational software interoperability is rapidly becoming an issue for users and developers of educational information systems. New software interoperability initiatives are under way in several domains of educational computing, including library automation, higher education information services, and K-12 performance support systems. A number of important issues face educational computing and information technology managers, developers, and researchers with regard to new educational software interoperability efforts.

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Rapid changes in computer-related technologies have had a profound effect on the organizational structure and operation of business, industry, government, and education. In each of these domains, the development of multiple new technologies, which support complex interactions with each other and with their constituent organizations, has been associated with human-factor and technological compatibility problems. One compatibility issue that has recently been discussed in the educational computing literature is the inability of most educational software applications to share standardized data with software from multiple suppliers, to work together to accomplish joint objectives.[1] In the computer industry, this type of multi-supplier compatibility is often referred to as "interoperability," and is considered a key enabler of networked, large-scale clusters of compatible hardware and software systems.[2]

Why care about interoperability?

There are several factors that impede the interoperability of educational software: the wide diversity in software product objectives, approaches, and performance; the expense of developing integrated systems; continuous obsolescence and new computer technologies in the field; and competitive pressures in the marketplace that compel software suppliers to be innovative, and to distinguish themselves from each other. Another impediment to the development of interoperability standards for educational software is the complexity of educational software environments.

Educational software systems are diverse, including administrative (such as financial, scheduling, and student information systems), productivity (such as word processing, communications, and presentation systems), and instructional (such as decision support, computer-based instruction, and information-retrieval

[1] See Clifford Lynch, "Interoperability: The Standards Challenge for the 1990s," *Wilson Library Bulletin,* March 1993, pp. 38-42. See also in the same issue S. McCallum, "Information Technology Standards: Implementation, Maintenance, and Coordination," pp. 43-45, and pp. 117-118.

[2] Some recent technical discussion of interoperability issues is found in Tony Stock, "Co-Existing With Alien Systems," *Computer Bulletin*, April 1994, pp. 12-31. See also Mauro Oliveira and Nazim Agoulmine, "Interoperability of Open Management Systems," *IFIP Transactions C: Communication Systems,* vol. C, no. 17 (1994): 209-224.

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systems) applications. Educational software operates in many separate worlds, from K–12 through higher education, each with unique databases, user-interfaces, and in the case of instructional software, assorted electronic media. Without strong evidence of potential benefits to justify the effort of generating and following standards of interoperability for educational software, both the developers and the users of educational software might avoid the issue, and as a result, miss out on the opportunity to benefit from meaningful, future-thinking, standards of interoperability.[3]

Standardization of educational electronic data communication, media formats, and eventually software applications, is under way within the educational computing industry, often driven by various user organizations and educational initiatives. Such standardization could eventually include the development of access to universal student records or performance data, information that may be useful at all levels of a person's education, and throughout a career. Although diverse applications continue to coexist in education, common interfaces with users and common data sources, created through the definition and development of standards of interoperability, are becoming increasingly important.

The success of educational interoperability standards will be particularly important if off-the-shelf instructional software, productivity software, administrative software, and even off-the-shelf "edutainment" software is to be successfully integrated with traditional educational systems, and with new distance learning networks, at the application level. Without interoperability, there will be no universal way to electronically manage and track the results of student usage of increasingly popular and available instructional software. By providing systemwide access to all electronic educational system data, interoperability in educational software has the capacity to electronically improve the focus of all components of education on the missions of the organization.

Case experience and anecdotal evidence in multiple electronic standards development initiatives both within and outside the field of education suggest that a strong argument for interoperability can be made. However, these evidences also raise a range of issues for educational computing managers, developers, and researchers. These issues must be understood if standards of interoperability are to be discussed and justified, and if users are to benefit from interoperable educational software systems through better achievement of educational missions.

New technologies and interoperability

To address the role of interoperability, one should consider first the difficulty of integrating new educational technologies into practice. Consider instructional software, for example. In most schools today, instructional software is used as a reward or a diversion, with little integration into the curriculum,[4] although the use of productivity tools such as word processors has been widely accepted in schools at all levels. The integration of more powerful instructional tools—such as computer-based instruction and micro-world simulations—into the average classroom has been slow and difficult.[5]

One reason often given for the lack of integration of computers into the mainstream of education is resistance to the use of technology by instructors.[6] Business and industry also experienced front-line resistance to the use of new technologies in the early years of automation, but through a continual dialogue between users and developers, the new technologies were successfully integrated with the front lines. One of the major accomplishments of this dialogue, and a key factor in the acceptance and integration of computer technologies in business, was their setting of, and following, standards of software and hardware compatibility between competing commercial suppliers, a combined hardware and software interoperability. As interoperability becomes a broader issue in educational computing at all levels, it is useful to consider examples of how interoperability has succeeded.

The Internet example

A successful example of interoperability is evidenced in the workings of the components of the Internet. In this case, software from multiple suppliers cooperates to manage a multitude of electronic networks, each connected to a common electronic backbone. While each of the software systems involved in a single Internet transaction may be supported by different hardware platforms and telecommunication software suppliers, by following standardized protocols, each transaction proceeds in a reliable fashion, handed-off across the various networks. The benefits of interoperability to the Internet are significant. The interoperability among the components of the Internet enable the creation of an enormous telecommunications infrastructure, facilitating the proliferation of global-area applications such as ftp and the World Wide Web.

The MIDI example

Another example of deliberately developed standards of interoperability is the musical instrument digital interface (MIDI) standard.[7] MIDI, an

[3] A good discussion of standards of interoperability is found in Lynch, op cit.

[4] An example of the lack of integration of computer-based instruction into the curriculum has been given by Poppy L. Pruett, "Utilization of the Microcomputer in the Mathematics Classroom," *Computers in Human Behavior* 9, no. 1 (1993): 17-26.

[5] For discussion of the problems of integration of technology into education, see Henry Becker, "How Computers Are Used in United States Schools: Basic Data from the 1989 I.E.A. Computers in Education Survey," *Journal of Educational Computing Research* 7, no. 4 (1991): 385-406. See also Tjeerd Plomp and Jef Moonen (eds.), "Implementation of Computers in Education," *International Journal of Educational Research* 17, no. 1 (1991): 1-121 (a special issue with nine papers on the use and integration of computers in education).

[6] Resistance to technology by instructors is discussed by Robert Hannafin and Wilhelmina Savenye, "Technology in the Classroom: The Teacher's New Role and Resistance to It," *Educational Technology* 33, no. 6 (1993): 26-31.

electronic network standard common in home, school, and professional music studios, was developed by a consortium of electronic music equipment suppliers, and was designed to allow all brands of computerized electronic musical instruments to use a common network interface at both the hardware and software levels. The high level of interoperability among MIDI-compatible electronic music equipment has made it possible for musicians to use an electronic music keyboard from any manufacturer that supports MIDI to control any other music keyboard, or electronic musical instrument with a MIDI interface.

The most obvious benefit of MIDI is that in most music studios today, one can find a mix of all kinds and brands of electronic studio equipment working together as components. With MIDI, musical equipment manufacturers and software suppliers specialize in their areas of expertise, yet their products work harmoniously with products from other suppliers to create a larger whole, an integrated, technology-supported music studio. With MIDI, electronic musical instrument manufacturers do not have to "re-invent the wheel" of the computer network interface between their devices.

MIDI has spawned a new genre of music technology firms that specialize in software that manages the composition and performance of music across MIDI networks. The quality and sophistication of products in the electronic instrument industry has leaped forward over the past decade, spurred on in part by user demand for the MIDI interface, as well as by the music and studio industry's acceptance of, adherence to, and promotion of the MIDI standard.[8]

The challenge for education

The successful integration of computer automation into the front lines of education, including, for example, the use of the computer-based instructional and microworld capabilities of computers in classrooms, requires a level of technical collaboration among educational stakeholders and participants that parallels efforts in the prior examples. The complexity of the information requirements of education is probably greater than the complexity of either the communication standards of the Internet, or the network standards of MIDI. The development of standards of interoperability for educational software requires the involvement of a menagerie of knowledge and information stakeholders. Education is, after all, a prodigious information industry.

Defining the standards of interoperability

In contrast to the enabling information-sharing standards used by the Internet, and by MIDI-based equipment in music studios, most educational software applications have no ability to share data, or to contribute student performance information to common databases. Educational computing is an enterprise of many applications tied together in educational goals, but not always linked in a technical sense, such as with software interoperability.

The importance of formally designing standards of interoperability cannot be overstated. When de facto standards arise, they often take on attributes of the lowest common denominators of compatibility, not serving the future interests of the field.[9] The development of a standard gauge for U.S. railroads is an interesting illustration of the resilience of de facto standards, and their resistance to improvement. If clear-thinking systems designers do not plan well for interoperability standards at all levels of educational computing, it is probable that the standards which do in time emerge (like the railroad gauges in the sidebar illustration) will be both inferior and difficult to displace.

Because commercial educational software manufacturers are subject to competitive forces, they cannot afford to develop standards without widespread agreement. For one or two firms alone, entry into interoperability agreements can become a liability, if other firms attempt to out-compete their standards, or create closed standards giving their existing products competitive advantage. It is important, therefore, in any standards effort involving commercial firms, to develop a consensus about long-term upward-compatibility issues, and maintain a level playing field for all participants, including the newest players as well as the established ones. Developing an understanding of theoretical and applied issues can assist in reaching this consensus about long-term interoperability needs. Such is the role that some system users, developers, and researchers are now seeking to play, as issues and opportunities in interoperability are identified.

Current interoperability efforts in education

Electronic interoperability has recently been achieved in several domains of educational computing. For example, the SPEEDE (EDI) standard has been developed in higher education for the electronic exchange of transcripts through a universal transcript definition.[10] Other examples within higher education are the communication protocol standards of MARC and Z39.50 used in library automation.[11] These application-level technical standards were developed in conjunc-

[7] For a discussion of using the MIDI standard, see Mark Ely, "Software for Classroom Music Making," *Music Educators Journal* 78, no. 8 (1992): 41-43.

[8] The fields of communication and education have both benefitted from the success of MIDI. See, for example, Gregory Jordahl, "Teaching Music in the Age of MIDI," *Classroom Computer Learning* 9, no. 2 (1988): 78-85. See also Brian Moore, "Music, Technology, and an Evolving Curriculum," *NASSP Bulletin* 76, no. 544 (1992): 42-46.

[9] See Judith Molka, "Surrounded by Standards, There Is a Simpler View," *Journal of the American Society for Information Science* 43, no. 8 (1992): 526-530.

[10] For a discussion of SPEEDE, see B. H. Palmer and P. Betty Wei, "SPEEDE Made Easy," *College & University*, Fall 1993, pp. 4-13; and E. W. Carson, "Electronic Transcripts—EDI in Academic Administration," *CAUSE/EFFECT,* Winter, 1991, pp. 3-7,15.

> "… most educational software applications have no ability to share data …"

tion with organizations such as the International Organization for Standardization (ISO, Geneva, Switzerland), the American National Standards Institute (ANSI, New York), and the National Information Standards Organization (NISO, New Brunswick, New Jersey). Another level of standard developed recently is the Open Software Foundation's Distributed Computing Environment (OSF's DCE). DCE technology will provide standards at the data access and network resource, or "middleware," level.[12] Further new technical standards, in early stages of development, will include a broader range of educational software.

The state of Florida, a pioneer in EDI in education through the Florida Information Resources Network (FIRN) system, a statewide network for the Florida education system, is seeking through the auspices of the Florida Schoolyear 2000 initiative[13] to extend the definition and utilization of standardized electronic educational information. This is being done through the creation of data flow control (DFC) standards, which new electronic learning support systems for Florida K–12 schools must adhere to, several of which are under development as part of Schoolyear 2000's Florida Learning Support System (FLSS) program.[14] Data flow control is an open access method for data that is "owned" by multiple software systems. A data flow controller has the ability to manage the access to data from various software systems from a variety of suppliers. The Florida Learning Support System data flow controller (FLSS-DFC) will interact with interoperable applications to automatically maintain and grant access to public data element dictionaries containing information such as data ownership, characteristics, locations, access privileges, and update requirements.[15]

The FLSS-DFC standard will initially allow electronic learning support systems of all varieties, and from multiple vendors, to interact and share data between all levels of educational systems, using standard protocols. Uniform data flow control will eventually extend to a host of other educational software systems, allowing for interoperability between and among various student information systems, instructional software systems, performance support systems, and administrative information systems at all levels of education in Florida.

There are a number of other recent and emerging standards that will facilitate the interoperability of educational software. These include data communication standards as well as various standards under development in the computer industry for multimedia interoperability. New multimedia standards efforts seek to

The Longevity of a De Facto Standard

The story of the U.S. standard railroad track gauge (the distance between the rails) is an interesting illustration of how de facto technical standards survive over long periods of time. The U.S. standard track gauge is 4' 8-1/2". The reason generally given for using this number is that the first U.S. railroads were built by English ex-patriots, and that was the gauge used in England at the time.

Most railroad historians believe that the English gauge for railroads was used because early English tramways had used the same gauge. Further, historians believe that tramway rails were spaced at 4' 8-1/2" because the builders of early tramway cars used the most logical existing tools and axle widths available to them, namely, tools and jigs available for the construction of horse- and oxen-drawn wagons.

As the story goes, wheels on wagons were generally spaced to travel securely in the ruts of the roads in Great Britain, which had been unchanged since Roman times. Wheels spaced any wider or narrower than the ruts in the road would never survive the shearing forces of the wagon, or chariot, traveling in and out of the ruts. Thus, the U.S. standard railroad track gauge may be attributable to the axle-width of the Roman war chariot, which was probably determined by the width of the typical Roman horse.

There were many attempts by innovative rail companies in the early years of railroading to widen the U.S. standard track gauge. The justification for the wider gauge usually given was that wider gauges lend more stability and allow higher carrying capacity. In the mid-1800s, cities and states often built rail routes with track gauges incompatible with their economically competing neighbor cities and states, running their own rail lines to important agricultural, shipping, and industry centers in an attempt to secure economic development. It was common for long-distance passengers and cargo to be unloaded and reloaded many times as they were transferred between railroad carriers on tracks of different gauges. Passengers and freight customers came to expect frequent "breaks in gauge," using local services for the unloading, across-town transportation, and reloading of the trains.

Debate about the inefficiencies of the well-established, incompatible railroad track gauges raged for over thirty years in the U.S.* Even Abraham Lincoln got involved, attempting to institute a standardized, wide-track gauge. The idea of a single track gauge standard eventually won the day, but the momentum of the narrower English standard, which by the 1860s was used on slightly more than half of the railways, was too great to ignore. In the 1880s the railroads were forced by growing national market forces to adopt the English standard, still in use in the U.S.

* The debate surrounding the integration of diverse, 19th Century American railroads is strikingly similar to current standards discussions in computing. For a fascinating treatment of this integration, see George Taylor and Irene Neu, *The American Railroad Network 1861-1890* (Cambridge, Mass.: Harvard University Press, 1956).

make multimedia file streams interoperable by allowing standardized multimedia data to flow across open networks for use by all compliant software applications.[16] Several interesting and important interoperability standards and potential standards across the scale of educational computing are depicted in Exhibit I.

The leading questions

A number of new standards of interoperability have been developed and implemented over the past few years, and more are on the horizon for education. A few questions related to

[11] For a discussion of these library automation standards, see the articles by Lynch and by McCallum, op cit.

(footnotes continued)

ongoing development of standards of inter-operability, and evaluation of new systems for interoperability capability, that should be considered by educational computing practitioners, developers, and researchers, are:

- What are desirable characteristics and models of computer integration for all aspects of education?
- What is the theory base for building and testing interoperability in educational software? In other words, what are we trying to accomplish?
- To what degree is the involvement of stake-holders at multiple educational levels, including K-12, vocational training, higher education, corporate training, and even independent schools, important for defining and developing various applications of interoperability, and for the ultimate pursuit of a computer-integrated system of education?

Other important questions are related to defining the missions of a technology-supported system of education. For example:

- What are the implications of interoperability in the practice of educational computing?
- What are the likely effects of educational software interoperability on the design of educational computer technology, its acceptance in the marketplaces of education, and ultimately on educational administration and learner performance?
- What is the role of interoperable instructional and educational software in a computer-integrated model of education?

As more and more electronic interoperability appears across the spectrum of education, students and educators should insist on answers to these questions, to assure that increased interoperability leads to more customer-centered, performance-oriented systems of education.

The future of educational software interoperability

For one illustration of how interoperability could provide useful and novel benefits to students, instructors, and administrators in the future, consider the situation in which an instructor would like students to experiment with off-the-shelf instructional software, perhaps even "edutainment" software such as "Where in the World is Carmen Sandiego™," "SimEarth™," or similar popular software titles. Perhaps through an interoperable instructional data interface, the instructor could some day receive information from these types of software that could help him or her understand the student's individual performance, information that could be used by the instructor to pinpoint future learning objectives for the student, or identify other instructional software that might

be useful. Overall student performance information could then be forwarded electronically to administrators, providing continuous indicators of educational mission accomplishment.

By sharing information about what was learned, or how well a student performed, a student's individual educational objectives could be partly met through interoperable integration of student information systems with off-the-shelf instructional software systems. More to the point, the computer-based aspects of education would become an enormous open system, facilitating the work of educators in meeting the needs of individual students through the use of interoperable software, including these types of popular software packages.

The management of software from a variety of suppliers via interoperable capabilities could increase educators' abilities to address individual needs. This would require industry-standard application program interfaces (APIs), and common approaches to data access. It would also involve evaluating the effects of integrating educational software, and learning how information from diverse genres of educational software can interact productively, coming from a field of diverse software suppliers. Such future applications could, as with the examples given earlier, create from the interoperable components a larger whole, an integrated, technology-supported system of education.

Meaningful interoperability

Perhaps the greatest challenge in managing and studying the development and implementation of standards of interoperability for educational software is to address the complexity of performance data in a manner meaningful to students, teachers, and administrators. This includes inquiry into the long-term costs and benefits in both time and money, of standardizing data among all educational software, from stand-alone software packages to global networks of educational databases. This also requires a perspective of the future, a view of an educational enterprise where educational technologies across all geographical boundaries could conceivably interoperate at a functional level. Such integrated systems could combine across distance learning networks to meet both the unique needs of each individual learner and the needs of society, a noble mission for educational systems.

A fundamental and ongoing discussion of interoperable instructional software in the field of educational computing and technology should identify which data elements are most important to be shared among systems of educational software. To reap the potential benefits of inter-

Exhibit I: Interoperability standards and potential standards across the scale of educational computing

The following table illustrates software interoperability standards in educational computing using the metaphor of a railroad to illustrate the hierarchy of standards. Some of these interoperability standards have been won after great market battles in the business world, while others have emerged quietly and comparatively quickly, after careful planning by standards and professional organizations. As educational software standards are beginning to diffuse across the scale of education, a technology-supported system facilitated by the full-scale interoperability of educational software is becoming a more real possibility.

Level/Scale	Railroad Metaphor	Example Standards
Communications Networks	Railroad track	Ethernet, ISDN, TCP/IP
Operating System Access	Standardized rail cars that carry standardized containers	DOS, Windows, System 7, UNIX, POSIX-OSE, OSF's DCE
General Information and Resource Sharing	Standardized cargo containers and passenger cars for various functions (dining, touring, sleeping)	Data Sharing: EDIFACT, SGML, SPDL, IRDS, SQL, new multimedia standards Communication: UUCP, ftp, HTTP/HTML
Application Information and Resource Sharing	Accommodations for typical railroad cargo in the standardized containers, and various types of passengers	Administrative: SPEEDE (ANSI X12), FLSS-DFC Library: MARC, Z39.50 Instructional: FLSS-DFC, many others needed in specialized discipline areas (such as MIDI in music education) Productivity: De facto file standards in word processing, spreadsheets, graphic images, CAD,etc.
Human to Computer Interface	Consistent and comfortable accommodations for passengers, and adequate tie-downs in the cargo containers	ISO 9241 (task, visual, form standards), various keyboard and icon layout standards, APIs for operating system access, GUI standards such as X Windows

Parts of this table are adapted from Judith Molka, "Surrounded by Standards, There Is a Simpler View," *Journal of the American Society for Information Science* 43, no. 8 (1992): 526-530.

operability, managers of educational computing and technology, as well as system-user organizations, developers, and researchers, must get involved in designing and managing systems in which multiple software modules utilize compatible user interfaces, data standards, application data interfaces, and most importantly, compatible indicators of student performance results. This will also include identifying evaluation criteria for interoperable systems based on current and potential user needs in a complex environment, an environment where suites of educational software from a variety of sources and suppliers can interact using common data sets, producing composite effects to help all educational organizations accomplish their missions.

Getting involved

Some of the issues surrounding standards of software interoperability in education have been recently addressed by various organizations involved in educational computing. Managers, developers, and researchers of educational computing, with regard to interoperable educational software, now have the opportunity to become involved in expanding the functional boundaries of interoperable systems, studying the usefulness of interoperability in multiple disciplines of education, and developing evaluation criteria for interoperable systems. This could include, for example, studying relationships between electronic student performance histories and other information-related aspects of the educational system available in an increasingly online educational world.

Some major tasks for researching, developing, implementing, and managing interoperable systems, as suggested and implied by this article, are outlined in the sidebar on the next page, including identification of some areas in which practitioners, developers, and researchers might be involved to help facilitate useful educational

jointly sponsored by the Florida Legislature, the Florida Department of Education, Florida school districts, and the Center for Educational Technology at Florida State University, Tallahassee.

[14] The initial description of this standard is contained in *The Florida Schoolyear 2000 Learning Support System, Program Announcement* (Tallahassee, Fla.: FSU Center for Educational Technology, 1994). See also the December issue of the *Heller Report on Educational Technology and Telecommunications Markets* (Highland Park, Ill.: Nelson B. Heller & Associates, 1994).

[15] Schoolyear 2000's Florida Learning Support System standards effort is being pursued through a multi-year co-development agreement between the Florida Department of Education (Tallahassee), and Encyclopaedia Britannica Education Corporation (Chicago). The co-developers are also working with a consortium of educational software suppliers to develop and further implement this data flow control standard. The data flow controller is being designed and developed by Information Systems of Florida.

[16] See Suruchi Mohan, "Multimedia Strives for Interoperability," *Computerworld,* 20 June 1994, pp. 72-3. See also Steve Rosenthal, "Multimedia to Play Across Platforms," *MacWEEK*, 6 August 1991, p. 78.

Tasks for designing, developing, and implementing interoperable systems

Design/Research
- Developing design requirements for educational software interoperability, including the identification of user needs, technology potential, desired outcomes for interoperable educational software designs, acceptable APIs, common approaches to data access, and universal formats for indicators of student performance results.
- Fostering the involvement of appropriate knowledge and information stakeholders in areas of education that could benefit from the increased information available in an interoperable, technology-supported system of education.
- Identifying or developing research tools capable of studying complex linkages between the elements of diverse educational software, and composite effects in the environment of a computer-integrated educational system.
- Developing core models for interoperable technologies, taxonomies for technology-supported systems of education that would integrate all educational software: instructional software, productivity software, administrative educational computing, automated quality systems, accountability and records systems, decision support systems, and others.

Development
- Identifying development issues through reviews of new standards of interoperability, and case studies of the design and implementation of new standards.
- Asking the right questions to assure that newly developed products will have the capability to become interoperable, and the interoperability will be designed to lead to a more customer-centered, student-performance-oriented system of education at all levels.
- Determining how diverse applications, including legacy systems, should coexist in an interoperable educational software environment.
- To fully exploit interoperability, identifying new educational software applications and opportunities made possible by common user interfaces and compatible data sources.

Implementation/Management
- Analyzing organizational and social issues related to the integration of interoperability and increased data availability into practice. This will include learning how to address the complexity of data from integrated systems in a manner meaningful to students, teachers, and administrators.
- Measuring the effects of various implementations of interoperability on: system performance, software features, product acceptance, and most importantly, user learning and performance.
- Defining evaluation standards and benchmarks for components of interoperable educational software systems.
- Determining soundness of implementations. Interoperability standards should be developed with input from those involved in the real-world implementation problems of the related hardware and software technologies.
- Analyzing the short- and long-term costs and benefits of educational software interoperability.

software interoperability. For example, an information manager might identify data elements of a student information system that are, or are not, legally available to interoperable software applications. By identifying data that could be shared among applications, new concepts can emerge, and systemic benefits could be far-reaching.

Pursuing a broader, more systemwide scope for technology management than is typical in education is critical if widespread interoperability is to make a useful contribution to the field of educational computing and technology. The computer-integrated educational system of the future will depend on complex webs of networks and linkages between systems. In the delicate human systems of education, where each component of the system has an effect on other elements in the system, deliberate inquiry into the designs of components of interoperable computer-integrated educational software will become increasingly important. Understanding issues of interoperability at all levels should prove an important new direction for educational computing and technology practitioners, developers, and researchers.

C/E