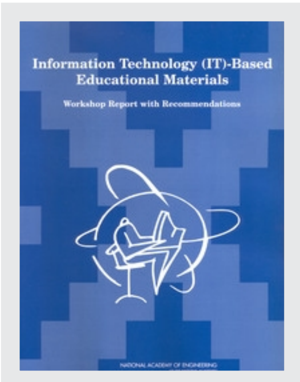

Information Technology (IT)-Based Educational Materials: Workshop Report with Recommendations

DETAILS

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Information Technology (IT)-Based Educational Materials

Workshop Report with Recommendations

Washington, D.C.
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Although the reviewers provided many constructive comments and suggestions, responsibility for the final content of this report rests solely with the study committee and the NAE.

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EXECUTIVE SUMMARY

One of the most persistent themes in education today is a call for new practices and new strategies to improve science, technology, engineering, and mathematics (STEM) teaching and learning. Concerns about the quality of STEM education reflect the general feeling that many opportunities for improvements through the use of information and communication technologies (IT)[1] have not been realized. To remedy the situation, a number of local and regional initiatives have been launched for using IT-based applications and tools in learning systems. The results of these initiatives have shown that IT-based approaches can be effective in educational settings. The promising possibilities of IT-based tools have also sparked the imaginations of faculty, learning scientists, entrepreneurs, business leaders, and political leaders around the world. One consistent hope shared by most stakeholders in STEM education is that, as IT-based systems mature, they will transform the teaching and learning environment.

A number of broad national initiatives have been launched to advance IT-based education, but so far IT-based teaching and learning is characterized by "islands of innovation," rather than overall change. Many innovations have been made, some of them successful, but they have only benefited limited, isolated audiences. So far, national coalitions have included several, but not all, of the constituents of STEM teaching and learning.

These initiatives have created a community of innovators, however, which has generated tools, products, and services. We have a window of opportunity to assemble highly advanced IT-based systems in support of education in a relatively short time if we can coordinate our efforts and agree on a strategic vision for the future. The workshop participants agreed that coordinated leadership will be necessary and that a national conversation should be focused on topics such as interoperability and shared objectives for the future.

This workshop sponsored by the National Academy of Engineering is an attempt to take advantage of the window of opportunity to promote a national discourse on the future of IT-based educational initiatives in post-secondary STEM education. The

[1] The term IT is used in this report to represent information and communication technologies.

outcome of these initiatives might also have significant implications for K-12 and continuing education.

About This Project

At the request of the Kavli Institute and in response to the growing concerns of leading educators in engineering and related disciplines, NAE established the Committee on Achieving Compatibility in IT-Based Educational Materials to explore ways of coordinating current initiatives into a coherent strategy for integrating advanced IT-based tools and resources into STEM education. At the request of the project sponsors, the committee convened a workshop of experts to discuss how broad compatibility for IT-based educational materials might be achieved. The committee outlined four general categories around which the workshop discussions were organized: architecture; tools and technology; content and pedagogy; and organizational, cultural, and legal issues. This report summarizes the themes that emerged from the workshop and presents the recommendations of the steering committee based on the workshop discussions.

In this four-month project and single workshop, the committee did not attempt to come up with a detailed plan to reach long-term, or even medium-term, goals for IT-based educational materials. The report recommendations are intended as guidelines for a meaningful conversation that could lead to: (1) broad interoperability for IT-based educational tools and resources; and (2) improvements in the quality of IT-based materials for STEM education. The overall goal is to transform the STEM educational environment. If the guidelines are followed, the coordinated conversations recommended in this report, coupled with lessons learned from pilot studies and other activities, could result in more detailed plans and strategies. This report presents a template for initial activities and policies.

The NAE Workshop

Of the several themes that emerged from the workshop discussions, the most significant was a broad consensus that past interactions between the technology community, the education-research community, and the community of practicing educators and learners have not been effective. A comprehensive solution will require a holistic approach to the problem, based, at a minimum, on coordinated communication among social scientists, learning scientists, end-users, and developers of IT-based educational resources.

The group also agreed that pilot programs based on the shared perspectives of teachers and learners should be established to identify the challenges to interoperability, open standards, and effective learning. These coordinated pilot programs should provide concrete examples that can inform continuing discussions.

Considering the complexities and enormous resources it would take to address the problems of multiple educational sectors, including postsecondary, K-12, and continuing education, the committee decided to focus this report on postsecondary education. However, the recommendations are largely applicable to other educational sectors.

Report Structure

The first chapter provides an overview of the problem, and an overview of the workshop discussions. The next chapter describes the existing patchwork environment in IT-based STEM education and the glaring lack of a unifying vision. One approach to addressing this problem is then described—identifying and filling the critical gaps in knowledge of the STEM learning process (particularly in an IT-context). Identifying the knowledge gaps will require a comprehensive strategy that aligns technical, cultural, organizational, legal, and economic objectives with educational objectives. Initiatives should be structured to ensure that programs can be sustained after initial funding runs out.

Chapter 3 describes a vision of IT-transformed education, characterized by a vibrant teaching and learning community and sustained by an environment and infrastructure that encourages continuous improvement in IT-based educational practices and products. The chapter includes a broad outline of a critical infrastructure: open architectures; community-defined technological specifications that support varying levels of interoperability; organizational and cultural strategies that nurture communities and support effective teaching and learning; and legal and economic frameworks that encourage openness and sustainability.

To ensure interoperability, cataloging and metadata can be used to locate and identify educational content. Learning-system initiatives would address the encoding of data for exchange among cooperative systems, as well as the semantics of learning content. To ensure the accessibility and usefulness of resources in a given environment several additional issues of interoperability will have to be addressed, including integration among systems within an enterprise, and with the needs of tool portability and the required modularity of applications within a system. In all of these cases, open specifications and standards will be essential to the shared development and use of educational resources.

The final chapter presents the recommendations of the steering committee. These high-priority actions are intended to establish a framework for strategic efforts to realize the envisioned educational environment described in chapter four. The appendixes provide the workshop agenda, summaries of workshop discussions, a roster of participants, and brief biographies of members of the steering committee.

Recommendations

The key elements of a strategy for transitioning from the current patchwork environment to the IT-transformed environment are presented in the final chapter of this report. The recommendations are based on three critical, interrelated elements of the strategy: building community, creating organizational enablers, and coordinating change. The report does not provide a detailed road map, which the committee believes should be developed with participation and leadership of leading national organizations. The initial strategy would provide a general plan for moving ahead. The major recommendations appear below.

Recommendation 1. A multidisciplinary, precursor committee drawn from stakeholders in STEM education should oversee the establishment of a comprehensive national strategy to achieve IT-transformed STEM education and the development of an engaged community that can modify (as needed) and implement the strategy. The precursor committee should be appointed by a national STEM organization, such as the National Academy of Engineering, National Academy of Sciences, National Science Foundation or National Aeronautics and Space Administration. The precursor committee should ultimately identify an organizational champion to serve as a long-term oversight body to coordinate future activities.

Recommendation 2. Follow-on workshops should be held to continue the discussion begun at the National Academy of Engineering workshop described in this report. The workshops should be coordinated and reflect the coherent strategy developed by a precursor committee of experts from all relevant disciplines. Workshop participants should represent all relevant constituencies, and the workshops should address issues related to interoperability, sustainability, and wide dissemination.

Recommendation 3. A precursor steering committee should identify and solicit the support of an organizational champion to carry out the long-term activities in support of IT-based STEM education. The organizational champion should be a significant presence in the STEM education community, and should carry out the strategy and vision set forth by the precursor committee. This would include the establishment and oversight of multiple communities and a national laboratory that supports research and development objectives for the advancement of IT-enabled resources and practices. The organizational champion should be a national organization such as National Aeronautics and Space Administration, National Institute of Standards and Technology, U.S. Department of Defense, U.S. Department of Energy, U.S. Department of Education, or a coalition of STEM professional societies.

Recommendation 4. All transitional initiatives should build on the Creative Commons framework, as appropriate.

Recommendation 5. A national laboratory should be established to pilot test IT-enabled resources and practices for STEM educational applications. The laboratory should engage leading scholars in research on fundamental processes in IT-enabled STEM learning, provide a test-bed for interoperability, and provide a mechanism for documenting the impact of specific resources and practices on STEM learning. The laboratory should be developed under the leadership of an organizational champion and with the support of leading government agencies (e.g., National Science Foundation, National Institute of Standards and Technology, U.S. Department of Defense, and U.S. Department of Education)

Recommendation 6. A targeted research agenda should be established for the development of social, educational, and economic models for improved STEM learning in an IT-enabled context. Details of the research agenda should be generated through follow-on workshops and funded by agencies involved in the advancement of research on STEM education (e.g., National Science Foundation, National Institutes of Health, U.S. Department of Education, and leading private foundations).

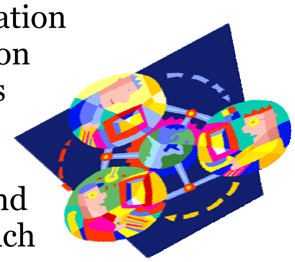
The ultimate success of this initiative will be measured by the response of leading government agencies and private foundations to the issues raised herein. As a result of activities and interactions to date, the committee has affirmed and strengthened its commitment to IT-transformed STEM education. The committee hopes this report will inspire similar commitments and excitement throughout the STEM education community.

ACKNOWLEDGEMENTS

The committee acknowledges the strong leadership provided by David Auston, president of the Kavli Institute, and Wm. A. Wulf, president of the national academy of engineering, in launching this timely and important dialogue. The committee also acknowledges the significant contributions of the workshop participants, the reviewers, and the staff of the National Academy of Engineering Program Office.

CHAPTER 1
WORKSHOP ON INFORMATION TECHNOLOGY (IT)-BASED EDUCATIONAL MATERIALS

In the last half-century, we have witnessed the birth and development of a new era—the information age. The era was ushered in by massive machines that could process simple mathematical operations that have evolved into a global network of technologies that can receive, process, share, and transmit information for a variety of purposes. Information technology (IT), the primary vehicle of the information age, touches the lives of almost every person. IT has transformed the modern workplace, is essential to the basic mechanisms of the world economy, is pervasive in the development of new knowledge and wealth, and has launched an entirely new vernacular. With each technological advance, the potential of IT to transform our lives further becomes even greater.



IT has also dramatically influenced our capacity to educate. IT tools are increasingly being used to automate administrative systems in secondary and higher education and to manage and assess courses. IT has made distance learning and asynchronous education possible by eliminating co-location requirements during the learning process. IT has also been used to link communities of practice, libraries, and databases, providing access to voluminous amounts of information that can be used by students to enhance their studies and by educators to construct teaching modules and texts. Most significantly, IT has led to tremendous advances in computing, simulation, and visualization—improving the teaching of advanced mathematics and facilitating visual representations of complex concepts and principles.

Despite the obvious benefits of using IT, the application of IT in education has been disorganized and uneven. Pockets of innovation in localized environments are thriving, but the promise of open access, greatly enhanced teaching and learning, and large-scale use has not been realized.

The purpose of this National Academy of Engineering (NAE) initiative is to realize the potential of IT-transformed science, technology, engineering, and mathematics (STEM) education as part of a vibrant, adaptive, educational enterprise. An IT-transformed educational environment has potential benefits for many disciplines, including engineering, the physical sciences, social sciences, liberal arts, and humanities. However, the focus of this report is on postsecondary STEM education. At the request of the Kavli Institute, NAE established the Committee on Achieving Compatibility in IT-Based Educational Materials to plan and implement a workshop on achieving broad compatibility among IT-based educational materials. It was hoped that the workshop would lead to a plan for the creation of a scalable framework and infrastructure that would encourage synergy, enable interoperability, and facilitate the dissemination of IT-enabled educational resources.

Based on the discussions at the workshop and their own experiences, the committee has developed a bold vision for an IT-transformed educational environment and has recommended a plan for moving toward a realization of that vision.

NAE sponsored a workshop to discuss the development of a plan to achieve interoperability for IT-enabled learning resources. The meeting was intended to provide opportunities for collaboration and networking and to facilitate discussions on the requirements for, benefits of, and challenges to achieving broad compatibility and transferability of existing and future IT-based educational materials in engineering and other STEM disciplines.

GOALS

The workshop had three goals:

1. Describe factors that could impede the reuse and sharing of IT-enabled learning materials.
2. Describe the environment (technical, organizational, and cultural) necessary for the effective sharing of e-learning components.
3. Identify strategies for realizing that environment and recommend high-priority activities.

FRAMEWORK

As a framework for discussion, the workshop was organized around four categories that affect the reuse, repurposing, and sharing of IT-enabled learning materials: architecture; technology and tools; content and pedagogy; and organizational, cultural, and legal issues. With these categories in mind, the committee generated an agenda and framing questions to guide workshop activities. Twenty-eight experts and leaders were invited to participate. The framing questions for each category are presented below.

Categories that affect the reuse, repurposing, and sharing of learning materials:
ARCHITECTURE
TECHNOLOGY & TOOLS
CONTENT & PEDAGOGY
ORGANIZATIONAL, CULTURAL, & LEGAL ISSUES

Architecture. The workshop addressed several questions in this area. What are the critical elements of an enabling architecture that can develop and distribute educational resources? How should learning objects be modeled and data be structured to achieve dynamic content? How can we ensure that content can be personalized and adapted to users' needs and that authorship can be traced and attributed? Can learner profiles be used to adapt resources to individual styles of learning? How can assessment data be incorporated to provide for continuous improvement? How can we ensure security, interoperability, scalability, and maintainability? Will the separation of content, display, and navigational functions make it easier to share resources?

Technology and Tools. In this area, the workshop focused on the impact of: (1) emerging horizontal standards (e.g., XML, XSLT, OWL, and the semantic Web) and vertical standards (e.g., IMS, MathML, and ChemML) for IT-enabled learning and (2) the management of rapid changes in technology/tools. How might we migrate from an environment based on (proprietary) legacy tools to a standards-based environment that promotes interoperable systems? What are the requirements for the development/authoring of tools that would enable rapid prototyping, ease of maintenance, content adaptation, and collaborative development?

Content and Pedagogy. How can objectives-driven and outcomes-based learning strategies be integrated into IT-enabled learning resources? How can IT-enabled learning resources facilitate the adoption of and improve the effectiveness of modern learning strategies, such as active, cooperative, and problem-based learning? How can IT-enabled learning resources be structured and documented to maximize the "sharability," reuse, and repurposing of the materials?

Organizational, Cultural, and Legal Issues. What are the cultural, organizational, and legal constraints that would limit the development of reusable, sharable learning objects? How can teachers and organizations that develop IT-enabled learning resources for open, unrestricted environments be rewarded? How can mutually beneficial online communities of learners and teachers be created? How can appropriate learning units (and outcomes) be defined and embedded to guide users in a variety of learning environments? Do network environments enhance or impede assessment? How can synergy, discourse, and exchange conducive to building a sustainable *commons of quality educational resources* be promoted? What are the preferred roles of different sectors (education, industry, government), and how should they interact?

Discussion and Results

Twenty-eight distinguished leaders in the development, use, and application of IT-based educational materials for STEM education participated in the workshop, which was held in Washington, D.C., on November 8, 2002. The workshop agenda and roster can be found in Appendixes A and B, respectively. The workshop was opened with a statement of the charge to the participants. Background presentations in each of the four categories (architecture; technology and tools; content and pedagogy; and cultural, organizational, and legal issues) followed. Each presentation was followed by open discussion to get a sense of the group's response to the issues raised.

During the afternoon session, participants were divided into small groups to discuss specific concerns in each category and to suggest action plans to address those concerns. Summaries of these breakout sessions can be found in Appendix C.

In the final plenary discussion, reports of the breakout sessions were reviewed, and participants attempted to come to a consensus. Several of the important, often overlapping themes that emerged from the discussion are summarized below:

- Building on existing programs and increasing collaboration will be critical to the long-term success of IT-based education. Building on successful efforts (e.g., the Creative Commons) should be a priority.

- A "national" strategy will be important for allocating resources to maximum effect.

- Workshops or other types of meetings would provide a mechanism for continuing the conversation(s) begun during this workshop.

- A national laboratory to facilitate the testing and sharing of IT-enabled educational materials would provide momentum and an operating framework for future development and would facilitate pilot programs and test-beds for data collection and analysis.

- A lead organization or "governing" entity will be important to the development of a unified community and to encourage change.

- Reforming cultural norms in STEM education will be critical. Reforms could include addressing faculty resistance to educational reform; skepticism about the efficacy of educational reform; reducing faculty resistance to the adoption of IT-based tools for teaching and learning; encouraging faculty to place a higher value on sharing, team orientation, and educational contributions.

In general, workshop participants agreed that the widespread use of IT-based educational materials will require holistic approaches. The committee further synthesized the discussion and developed a plan to move forward.

Post-Workshop Activities

The steering committee met the following day to review the discussion and develop succinct statements of the themes that emerged at the workshop. Taking each of the workshop goals as a separate charge and pulling together suggestions and concerns raised during the workshop, the committee outlined a vision for an IT-transformed educational environment and recommended first steps toward achieving that vision. The remainder of the report is organized around three general categories that are closely related to (but not identical to) the four discussion categories. The three categories are: technology and tools infrastructure; content and pedagogy; and human, cultural, and organizational issues. The holistic nature of the strategies are reflected in the discussions and in the final recommendations.

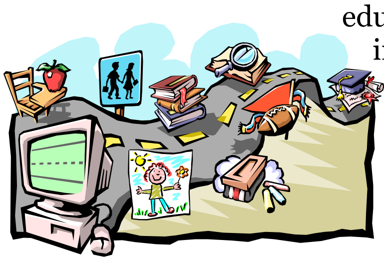
CHAPTER 2
OUR CURRENT STATE: ISLANDS OF INNOVATION

Many STEM educational programs and institutions have been involved in projects to improve teaching and learning through the application of IT. The resulting IT-based learning materials have proven to be adaptable and dynamic, and in many cases they have enhanced the educational process. A growing number of people are involved in the development of IT-based educational materials. The landscape of STEM education is now dotted with *islands of innovation*—isolated areas where IT-based materials are being used effectively. However, not all innovations have led to more effective learning because these materials are often used by limited numbers of users. Thus, opportunities for synergy, discourse, and exchange—steps that often lead to improvements in next-generation products—have also been limited.

Impediments to realizing a desirable environment for IT-based educational materials are complex. Multidisciplinary strategies for improving IT-enabled products put forward by workshop discussants addressed technological, cultural, legal, and economic issues. The following sections include brief descriptions of the existing environment for developers and users and the challenges that must be overcome. For the sake of discussion, the challenges are organized into three broad categories: technology and tools infrastructure, content and pedagogy; and human, cultural, and organizational issues. The reader should keep in mind, however, that these issues are inextricably intertwined.

TECHNOLOGY AND TOOLS INFRASTRUCTURE

The Internet has provided a technological basis for simple sharing of IT-based educational materials. The more difficult problem of interoperability will require common protocols and standards that enable machine communication at an operational level. Hence, technological constructs (e.g., architecture, standards, and tools) will be key enablers for achieving broad interoperability among IT-based educational materials and tools.



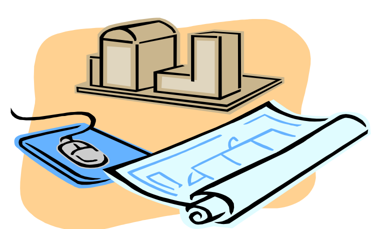
Architecture and Standards

Our current environment, which can be characterized as islands of innovation in computer-enabled learning, reflects disparate efforts by individuals, groups, university-wide communities, and multi-university coalitions. A number of parallel initiatives are already defining horizontal (e.g., across domains or disciplines) standards for learning objects. Examples include the Sharable Content Object Reference Model (SCORM) standards for web-based learning applications, the Instructional Management Systems Global Learning Consortium (IMS) standards for online distributed learning networks, and the World Wide Web Consortium (W3C) specifications for the web infrastructure. Other bodies such as the Institute for Electrical and Electronic Engineers (IEEE), the International Organization for Standardization (ISO), and other organizations are also involved in the establishment of technical specifications and horizontal standards.

The SCORM, IMS, and W3C standards are being created by a global network of researchers, developers, and users, with a broad objective of creating an infrastructure to support interoperability. However, none of these initiatives has gone much beyond providing functional educational services, such as course and student administration, content management, and course assessment. None of these has focused on advancing the teaching and learning process. Expanding these initiatives to address core teaching and learning activities (e.g., advanced, domain-based applications and services) would increase their potential impact on the teaching and learning experience. But, this would require greater participation by researchers in the learning sciences and social sciences, as well as by classroom educators and students (i.e., end-users).

Digital repositories are just one of many examples of portals that provide content materials for large numbers of educators. These repositories contain digitally stored, archival materials that are available to all, or selected, educators and students. The materials are structured in an agreed upon format to provide easy archiving and sorting. Information is embedded through structured metadata sets to help users apply the materials appropriately (e.g., learning objectives, assessment strategies, and pedagogical approaches, etc.).

The National Science Foundation (NSF) National Science, Math, Engineering, and Technology Education Digital Library (NSDL) and the Multimedia Educational Repository for Learning and On-Line Teaching (MERLOT) are two examples of digital repositories with a national scope. NSDL and MERLOT serve online communities, and NSDL provides a defined structure to guide the development of new materials. NSDL and MERLOT have also begun to address some of the content issues identified at the workshop, such as, the establishment of a framework for instruction



guides (i.e., tutorial aids), the creation of metadata vocabularies for describing material content and purpose, the provision of assessment aids, the embedding of pedagogical information, etc.

NSDL and MERLOT and similar initiatives are still in their infancy; much more must be done to bring about their widespread adoption. One important contribution of NSDL, MERLOT, and related efforts has been the integration of advances in learning science into IT-based educational modules. The involvement of learning and social scientists represents an important step forward. The digital library community could be an important source of leaders and researchers as we move forward.

As described above, current learning management systems tend to concentrate on the administrative aspects of courses and content and the presentation of materials, rather than on advanced teaching and learning activities. A few attempts have been made to include advanced learning services, but many of these are in their infancy. As current efforts have shown, achieving interoperability will not be a simple task. Portability and the sharing of learning objects will require service definitions and definitions for data interchange. At present, however, widely accepted frameworks for structuring and specifying content and metadata for learning services are limited in scope. A related concern is that, unless and until specifications are agreed upon for a broader range of educational services and applications, we can expect inconsistencies in technical approaches and fragmentation to increase. All of these problems are aggravated by the rapid changes in the technological environment; learning materials quickly become obsolete unless they can be translated into next-generation formats.

Content Modules and Tools

Content modules include digitally encoded lessons on specific topics, assembled textbooks, and interactive displays of information based on inputs from users. Tools are used to help users build new modules, adapt existing modules for new purposes, and assemble collections of modules to for a specific educational activity.

NSDL and MERLOT are large-scale initiatives that store educational content for STEM educators. There also are numerous examples of more localized initiatives that apply IT in the service of STEM education. Connexions at Rice University has developed its own modular approach for delivering domain-specific lesson materials to engineering faculty. The Sooner City Project at the University of Oklahoma is an online curriculum for civil engineering students from freshman through senior year.

Every year, the American Society for Engineering Education (ASEE) recognizes outstanding educational courseware through its Premier Award for Excellence in Engineering Education. This is an indication that good quality materials are available for those who happen to be in the right place or with the right instructor.

Excellent materials that cover a wide range of advanced, domain-specific lessons using IT-based modules could be made available to other educators over a shared network. However, very little is being done to encourage dissemination (e.g., providing instruction and other support services for other users). Thus, the use of these materials at other campuses, in other departments, or even in other classes has been very limited.

Many of the tools for authoring, repurposing, maintaining, and distributing learning content do not use technology consistently to support content-oriented markup. For example, many people are familiar with web-authoring applications, such as Adobe PageMill, Microsoft Frontpage, and Macromedia Dreamweaver, that produce hypertext markup language (HTML) code to support user-defined web page displays. But these applications are also notorious for numerous quirks in the creation of objects, tables, frames, and other display features. One fundamental problem is that HTML itself is a display markup language (i.e., it lets the computer know what the display should look like), but it cannot communicate information to the machine about the use and purpose of the content. By contrast, other markup languages, such as extensible markup language (XML), are designed to let the machine know what the content is and how it is used.

One next step for IT-developers could be the development of authoring and repurposing tools that use content-oriented markup languages (CoML). A CoML approach would allow machine-level communication using structure sets that emphasize educational objectives and outcomes. Ongoing improvements in other tools, such as Web-based Distributed Authoring and Versioning (WebDAV), could enable the cooperative development of materials through online mechanisms.

Content and Pedagogy

The core communities that comprise an IT-enabled teaching and learning environment are authors (including the complete IT-development team), teachers, and students. Each of these communities has its own culture, its own needs, and its own support structures and resources. In a traditional educational setting (i.e., a classroom with teacher and students), learning is primarily dependent on the teacher and student communities converging around common themes and objectives. In IT-enabled environments, the learning model (at least for now) is dependent on a convergence between the student, teacher, *and* author communities.

In spite of increasing evidence that a learner-centered model results in better knowledge retention and comprehension, STEM education is largely based on teacher-centered models. Resistance to the adoption of learner-centered models in STEM teaching cannot be addressed by simple solutions. First, the shift to a learner-centered environment could interfere with the traditional focus of STEM institutions on technical research; this focus is generally reflected in incentive and reward systems and other institutional, physical, and human infrastructures (this issue is discussed further in the following section on cultural issues). Second, only a fraction of existing STEM faculty are knowledgeable about existing cognition and learning models relevant to STEM disciplines. Thus faculty training and education will be necessary for a scale-up of learner-centered education. Third, a good deal about how people learn STEM concepts, both inside and outside an IT context, is still unknown. A better understanding of how STEM concepts are initiated and processed in the human brain would go beyond the application of active techniques (e.g., problem-based learning, interactive and collaborative learning, and service-learning) and beyond models for tools such as language tutors.

The workshop participants agreed on the need to embrace a scholarship of learning to create the intellectual capital that would support effective STEM education and the development of better tools to assess STEM learning outcomes.

Human, Cultural, and Organizational Issues

Even if we had easy-to-use tools for developing content, efficient architectures that supported sharing and reuse, and valid pedagogical models for achieving advanced STEM learning outcomes, there would still be significant barriers to the use of IT in the service of education. Human, cultural, and organizational concerns present significant challenges to the use and dissemination of IT-based educational tools and materials. Many of these issues, outlined below, have been discussed in non-STEM domains, but they have been largely absent from discussions on the use of IT in STEM education. Until these issues are addressed, the outlook for meaningful progress is limited.

Learning to Learn With IT

From preschool and kindergarten through secondary school, educational institutions are primarily equipped to support non-IT-based teaching and learning experiences. In spite of the explosion and popularity of electronic games and electronic learning aids for all students, beginning with pre-schoolers, and despite the modern practice of including CDROM textbook supplements, references to internet sites in textbooks, and other electronic features to enhance texts and other traditional educational materials, most students and teachers have had minimal exposure to IT-based practices and resources in the classroom. Moreover, once students and teachers have developed successful classroom learning strategies, they expect to continue learning the way they have always learned.

Teachers and students who have developed learning skills adapted to non-IT learning environments, often find developing the skills and strategies for learning in IT-based environments uncomfortable, or even onerous. This resistance can be partly overcome by appropriate training and practice schedules; but people are resistant to change unless they perceive a benefit. Because faculty members have greater influence over the incentives that motivate students (and parents) (i.e., grades), strategies should target adoption by faculty of IT-enabled educational approaches.

A related factor is that successive generations are more comfortable with the electronic environment. Many students have had access to computers and other electronic aids since preschool. But, only the youngest faculty members had access to user-friendly computers during the formative years of their education. Therefore, programs should be designed to transition faculty to an IT-enabled paradigm. And even though in time the situation will change naturally, the glacial pace of cultural change in academia could be accelerated by deliberate actions and strategies.

Holistic Approaches

Many people are just beginning to recognize the benefits of IT-based resources and practices in education. Faculty who have embraced IT are beginning to seek out and interact with others who share their unique ability to envision and implement IT-enabled innovations. However, the majority of faculty and administrators appear unconvinced that the benefits of IT-based innovations justify the costs of implementing them.

One theme that emerged at the NAE workshop was that in the future, IT-based materials and strategies must be easier to learn, easier to use, and better supported. The challenge is to develop sustainable solutions that merit the investments required to use them. This will require that developers pay more attention to overcoming the full set of barriers in the STEM education culture.

An important lesson that has been learned in other (non-STEM) environments, and that was repeated often at the workshop, is that current practices, beliefs, and assumptions must be characterized before interventions for behavioral change can be developed. Social models for growing and nurturing communities of practice—collective groups of practitioners united by a common goal—and models for realizing specific behavioral changes in target populations or organizational cultures have been developed. However, they have rarely been applied to STEM educational environments. Thus, a period of learning and adjustment may be anticipated.

Past experience has shown that cultural, linguistic, and political differences among teachers and students in STEM education are very important. For example, women and underrepresented groups leave (or choose to not enter) STEM programs at higher rates than majority male students. Studies have shown that academic achievement is not the most significant factor in their decisions. Cultural factors, such as classroom climate, the quality of teaching, and the lack of social acceptance are more important factors[2, 3]. Investigations into the cultural factors that influence the success of IT-enabled resources and practices in STEM education may reveal equally unexpected conclusions. The workshop participants agreed that widespread success without a rigorous understanding of cultural influences.

Institutional Culture and Leadership

The institutional culture (the culture that supports the fundamental mission of an organization), is reflected in the incentive and reward system, as well as in the institution's support structures. Although STEM institutions have been urged to embrace IT-based education, they have been reluctant to change their underlying culture. Workshop participants identified changes at the institutional level that could encourage the use of IT in education. IT-based activities thrive in open environments, but STEM institutions have traditionally been creators, collectors, and repositories of knowledge; the emphasis has been on "ownership." An IT-pervasive environment requires openness and sharing. STEM educational institutions must be encouraged to adopt knowledge creation, knowledge sharing, and knowledge dissemination as fundamental components of their mission.

Initiatives such as Open Course Ware (OCW) and DSpace are examples of institutional commitments to support the broad dissemination and sharing of learning materials through online media. The Creative Commons initiative is an example of a structure that supports users who wish to provide open access to learning materials and addresses the most common obstacles related to ownership and intellectual property rights. At present, only a few organizations participate in OCW, DSpace, and Creative Commons, but the success of IT-enabled education will depend on bold initiatives like these that allow for the easy exchange of ideas and the freedom to build upon the work of others.

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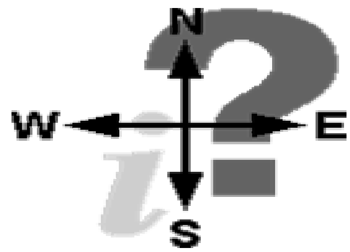
[2] See Seymore, J. and N.M. Hewitt. 1997. Talking About Leaving: Why Undergraduates Leave the Sciences. Boulder, Colo.: Westview Press.

[3] See Adelman, C. 1998. Women and Men of the Engineering Path. Washington, D.C.: Department of Education.

Another difficulty is the diversity of institutions involved in STEM education, which includes private schools, public schools, four-year colleges and universities, community colleges, etc… This broad range of environments presents tremendous technical and social challenges because cultural solutions usually require designs tailored to specific environments.

Another recurrent theme that emerged at the workshop was the need for a national organization to take the lead in advancing the use of IT in STEM education. The champion organization would bring together stakeholders and diverse experts to collaborate in the development of strategies and solutions for advancing the use of IT in education. The success of the Internet Engineering Task Force (IETF) in providing an organizational framework for advancing the Internet provides some useful parallels that can inform efforts for IT-based STEM education. IETF working groups, organized under an umbrella subcommittee, are responsible for the development of Internet standards and protocols in areas such as routing, applications, and security. A parallel committee identifies research priorities to advance the broad goals of IETF. A similar framework to support IT-based STEM education would fill an enormous leadership vacuum in today's environment.



Legal Issues

Existing copyright laws and intellectual property laws are not compatible with an open system for IT-transformed education. Assignments of credit, commercialization, and ownership to individuals, groups, and institutions involve complex issues that must be addressed. In the event that laws and practices have to be overhauled, the aforementioned Creative Commons initiative is a good starting point for generating tools and strategies for the open sharing of information and the development of IT-based educational materials. The workshop participants noted that organizational priorities and reward structures would also have to be realigned accordingly.

Financial Issues

Our understanding of the economic models that could sustain an IT-transformed educational system is limited. It is apparent that up-front investments in physical and human infrastructure will be necessary, but the economic impact of large-scale changes in the faculty reward system and the faculty culture is not well understood. Uncertainty about the economic impact is a significant deterrent to change, particularly in difficult economic times. There is a real danger of “overselling” it-based education or promising more than can be delivered. Based on the experience of the artificial intelligence community, we know that plausible systems should be developed before large-scale changes are proposed. And based on the difficulties encountered by the NSF engineering research centers and engineering education coalitions, we know that we must create an economically sustainable infrastructure to make a lasting change.

CHAPTER 3
THE NEW ENVIRONMENT:
IT-TRANSFORMED EDUCATION

Future Vision
An IT-Transformed Educational Environment

A robust suite of modular, IT-based resources supports a dynamic, distributed, and flexible learning environment. Built on open system architectures and machine-understandable semantic models, these resources are interoperable, sharable, easy to use, easy to modify, and widely disseminated; they underpin a vibrant teaching and learning community and enable a sustainable ecology for continuous improvements in educational practice. A rich array of technologies and approaches form the scaffolding for further modifications to the learning environment, enabling the optimization of educational practices for their effectiveness rather than for simple efficiency. The elements that support the learning environment integrate advanced knowledge about technology, people, processes, and organizations.

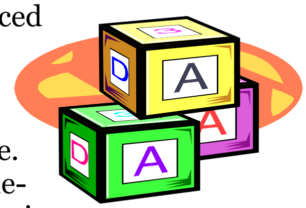
As IT-based educational materials continue to mature, thoughtful strategies for the integration of these materials into the classroom and learning experience can transform education, making it more efficient and more effective. This section describes the key elements of an IT-transformed educational environment identified at the workshop and by the committee. The IT-transformed environment can be characterized as a *sustainable ecology of IT-enabled learning resources and practices* that have evolved through the consensus of an active community of authors and users, informed by an evidence-based understanding of effective teaching and learning. Achieving this goal will require sustained leadership and support from the leading STEM organizations and agencies.

TECHNOLOGY AND TOOLS INFRASTRUCTURE

In the envisioned future, IT-enabled learning resources will be seamlessly integrated into the teaching and learning environment. These resources will be broadly disseminated, readily sharable and interoperable, and based on community-defined guidelines and structures. Interoperability will be a priority in the design and development of learning resources, and continuous improvements of these materials will be supported by published cases that encourage intellectual discourse and the identification of scalable, sustainable best practices. The examples of best practice will guide ongoing development, encourage dissemination and diffusion, and ensure quality.

Services-Based Architectures

In the world of IT-transformed education, advanced learning objects are the building blocks of IT-enabled educational materials. Advanced learning objects will be developed based on community-defined requirements for a services-based architecture that supports varying levels of interoperability and emphasizes operational communication and data exchange. Advanced learning objects will contain machine-understandable, semantic-driven models and vocabularies that provide information on systemic behavior, user profiles, context, and pedagogy. The embedded data will be characterized by open markup formats that reflect standards for machine-supported communication and interoperability. The standards will also be designed to address a complete set of user-support requirements: application context (e.g., by discipline, course level, sector, etc.); instruction (e.g., tutorials, evaluation history, help resources, etc.); attributes (e.g., learning style, gender, world view, etc.); pedagogy (e.g., objective, learning outcomes, assessment, etc.); and other preferences (e.g., display, configuration, etc.).



Tools for Creating and Adapting Educational Materials

A rich set of tools that enable the creation, modification, and adaptation of existing educational materials will be open and accessible. These tools will enable useful services, such as navigating, search and archival services, and translation between formats. The tools will also support migration from legacy formats to adaptive formats, thereby decreasing the support requirements for next-generation products.

CONTENT AND PEDAGOGY

STEM educational practices will have a learner-centric orientation and will reflect advanced, evidence-based knowledge on learning and cognition. IT in the service of STEM education will be an inherent (i.e., transparent) mode of thought, communication, and application for teachers and students. Ongoing interactions between authors and users (including teachers and students) of IT-enabled teaching and learning resources will be mutually beneficial. These discussions will lead to new IT-enhanced educational practices that will then be widely adopted in formal educational settings.

Discussions between authors and users will also lead to the development of user-friendly tools and supports (e.g., modular formats for documentation and user support). Acquiring learning materials and supports from regional, national, or international groups and communities will be a regular practice.

HUMAN, CULTURAL, AND ORGANIZATIONAL FRAMEWORKS

IT-based teaching and learning practices will be generated by an active community of authors and users who create, share, and modify IT-enabled educational materials. This community will embrace a scholarship of teaching and learning and will have a continuing goal of advancing learning. Efforts to advance the STEM learning experience will enjoy strong support among academic, government, and industry institutions and officials.

Organizational Framework

A central governing body at the core of the community will be an organizational champion with a mission of improving efficiency and effectiveness, ensuring integrity and quality, and promoting the dissemination and use of IT-enabled learning resources and practices. The governing body will represent the concerns of the community to government and other agencies and will lobby for resources and other critical infrastructures to support IT-enabled education. The governing body will also oversee a program of coordinated activities to facilitate dialogue on research priorities, best practices, strategies for dissemination and adoption, and assessment and evaluation. In its coordinating role, the governing body will recommend complementary roles for community sectors (i.e., government, industry, academy) to maximize available resources. The governing body will also propose and oversee active projects to develop new ideas, pilot new innovations, and document performance and/or impact on the learning process. An existing model that approximates this governing body is the Internet Engineering Task Force, which has a strategy of pursuing "working code and rough consensus."

Cultural Framework

In the future, educational institutions will be transformed into centers where knowledge creation, dissemination, and sharing are equally valued and emphasized. These values will be reflected in the incentives for meeting each of these objectives; incentives for improving teaching and learning will be commensurate with incentives for technical research.

Legal Framework

The dissemination of IT-enabled teaching and learning resources will be supported by a novel legal framework (e.g., open licenses and attribution systems) that promote creation and sharing, while maintaining incentives for authors (including individuals, teams, and institutions) to create and distribute or assemble and reuse high-quality learning materials. Because the value of dissemination, interoperability, and sustainability is recognized by all, they will be priorities in the design and development stages of new materials. Research and development practices, reporting (publication), and documentation for the larger community will reflect these priorities.

Chapter 4
WORKSHOP RECOMMENDATIONS

One strategy for moving from the current patchwork environment with its "islands of innovation" to an IT-transformed educational environment is to create a sustainable ecology for ongoing improvements in IT- enabled educational resources and practices.

High Priority Actions:
i. Build Community
ii. Create organizational enablers
iii. Coordinate change

The steering committee and workshop participants recognize that the desired changes will be difficult to achieve, and achieving them will require coordinated action that brings together all of the constituents to STEM education and IT product development. The committee concluded that generating a detailed road map would not be appropriate at this time. Instead, a series of transitional activities should be undertaken to lay the groundwork for change and to define future actions and initiatives. The recommendations can be divided into three high-priority actions: (1) build community; (2) create organizational enablers; and (3) coordinate change.

BUILD COMMUNITY

An active, informed community is essential to an IT-transformed educational environment. An active community would support dissemination and diffusion by encouraging discourse and networking around the development, use, understanding, and sharing of IT-enabled learning resources.

Precursor Committee on IT-Enabled STEM Education. Cultivating community must begin by establishing open, ongoing communication between targeted groups around issues of common interest. Establishing an interim committee that would bring together experts and forward-looking leaders representing the key stakeholders in IT-based STEM education will bring national attention to the objectives, and spark the interest of a broad spectrum of researchers. The interim committee should coordinate initial activities and generate a detailed plan, pursue the resources necessary to carry out the initial activities and plans, and identify a permanent organizational champion to carry out the long-term plans. The interim committee should be sponsored by one or more organizations that have significant influence on STEM education (e.g., NAE, National Academy of Sciences, NSF, and National Aeronautics and Space Administration).

Follow-on Workshops. A first step for launching detailed discussions on IT-enabled STEM education is to hold follow-on workshops to: (1) extend the dialogue initiated in the NAE workshop; and (2) promote communities of practice that can define the critical challenges and other issues related to the improvement and use of IT-based educational materials. The critical groups in the discussion will be IT-developers, users (teachers and students), researchers in education, and college administrators. The objectives of the workshops should reflect a coordinated strategy, as determined by the precursor steering committee. The workshop discussions should result in the generation of a detailed plan for achieving broad interoperability, effective learning outcomes, and sustainable solutions. Some of the following topics could be addressed in the workshops:

- outline the critical challenges to integrating systems and research among key stakeholder communities in IT-based STEM education, including the alignment of technical, human resource, cultural, organizational, and economic practices with educational objectives

- identify scalable best practices in IT-enabled STEM education

- develop plans for generating new intellectual capital on effective IT-based pedagogies in STEM education

- identify and discuss issues related to the increasingly global context of STEM education and practice

Recommendation 1. A multidisciplinary, precursor committee drawn from stakeholders in STEM education should oversee the establishment of a comprehensive national strategy to achieve IT-transformed STEM education and the development of an engaged community that can modify (as needed) and implement the strategy. The precursor committee should be appointed by a national STEM organization, such as the National Academy of Engineering, National Academy of Sciences, National Science Foundation or National Aeronautics and Space Administration. The precursor committee should ultimately identify an organizational champion to serve as a long-term oversight body to coordinate future activities.

Recommendation 2. Follow-on workshops should be held to continue the discussion begun at the National Academy of Engineering workshop described in this report. The workshops should be coordinated and reflect the coherent strategy developed by a precursor committee of experts from all relevant disciplines. Workshop participants should represent all relevant constituencies, and the workshops should address issues related to interoperability, sustainability, and wide dissemination.

CREATE ORGANIZATIONAL ENABLERS

Discussions and workshops are important for building community and expanding the ideas brought forward at the initial NAE workshop, but sustainable change requires coordinated action and a stable organizational base. For this reason, the workshop suggested establishing a lean organization to spearhead an evolving action plan over time. This organization must work cooperatively with existing technology-focused and educational groups and coordinate the development and implementation of a national strategy.

Identify an Organizational Champion

A national organizational unit (e.g., U.S. Department of Defense, National Institute of Standards and Technology, U.S. department of Energy, U.S. Department of Education, or a coalition of STEM education professional societies) to champion and coordinate activities beyond the precursor stage will ensure that the activities and goals of various groups (or communities) are coordinated and leveraged. The organizational champion will promote the advancement of IT-enabled learning to the public and private sectors and cultivate unifying goals and objectives among the various stakeholders to IT-transformed STEM education. The success of the Internet Engineering Task Force, with its "rough consensus and working code approach," provides some useful parallels that can inform efforts in IT-based STEM education. The organizational champion should also oversee a national laboratory for research on IT-enabled educational resources and practices (described below).

Build on Creative Commons

Existing policies and legal frameworks for intellectual property are significant inhibitors to collaborative efforts in IT-enabled resources. Creative Commons, which focuses on openness and sharing, could be a workable model for moving from the current patchwork environment toward an environment that promotes a commons for creativity and dissemination.

Recommendation 3. A precursor steering committee should identify and solicit the support of an organizational champion to carry out the long-term activities in support of IT-based STEM education. The organizational champion should, a significant presence in the STEM education community, should carry out the strategy and vision set forth by the precursor committee. This would include the establishment and oversight of multiple communities and a national laboratory that supports research and development objectives for the advancement of IT-enabled resources and practices. The organizational champion should be a national organization such as National Aeronautics and Space Administration, National Institute of Standards and Technology, U.S. Department of Defense, U.S.

Department of Energy, U.S. Department of Education, or a coalition of STEM professional societies.

Recommendation 4. All transitional initiatives should build on the Creative Commons framework, as appropriate.

COORDINATE CHANGE

Although significant efforts are under way to develop technologies and applications for sharable learning resources, these efforts are not coordinated to better ensure the creation of a shared educational delivery system comprised of people, organizations, and tools. The development of enabling technologies for operability will not be enough to fill this gap. The ultimate challenge will be to achieve *inter*operability to support learning. This will require holistic approaches that address the full range of factors that impact the educational experience.

A National Laboratory for IT-Transformed Education

A national laboratory would provide a real context and an open environment to pilot, test, and evaluate IT-enabled resources for STEM educational purposes. A sustained, highly visible laboratory would establish an infrastructure that supports community exploration of diverse components and processes of the IT-enabled educational experience. The laboratory would also enable research that meets the highest standards of scientific exploration, thereby supporting evidence-based advancements in the reform of STEM education. One model for this laboratory might be the Fermi National Accelerator Laboratory (Fermilab), a national laboratory where scientists examine basic questions about the smallest building blocks of matter. Like the Fermilab, the IT laboratory would bring together outstanding scholars from many disciplines to study fundamental academic questions in IT-enabled STEM education: (1) the fundamental processes of learning with IT; and (2) achieving sustainable IT-based education in a STEM-relevant social environment.

The laboratory, which would exist in both virtual and physical space, would bring together distributed research on education, learning, and technology; and it would establish a virtual commons for diverse initiatives (e.g., OKI, IMS/SCORM, digital libraries, iUniversity, Connexions, and Sooner City Project) and link the efforts of pioneering developers and practitioners. Functioning as a test-bed and proving ground, the laboratory would bridge the gaps between research, standards initiatives, and the implementation of products. The laboratory would also facilitate data collection and scalability and encourage the adoption of standards-based learning resources through examples and demonstrations. The laboratory would provide a mechanism for sharing experiences and would support the development of quality educational resources. It would enable the identification of exemplary tools and processes and establish a beginning basis for interoperability.

A detailed organizational structure and work plan should be developed for the laboratory before the laboratory is established. The organizational champion should be responsible for planning and implementing activities leading to the laboratory's creation. Initial activities would be focused on current projects and available tools, but, as the laboratory informs and catalyzes developers, vendors, and adopters, it would become a spawning ground for new tools and new investigators.

Research Agenda that Includes Education and the Social Sciences

By combining advanced anthropological, psychological, and sociological research with other research strands in IT-based STEM education, the national laboratory effort, implemented in a distributed model format (e.g., located across diverse institutional types), will be ideally suited to provide insight into the human and organizational challenges associated with the use and deployment of IT-enabled learning resources. Research programs that integrate social and technical studies of effective STEM teaching and learning would reflect the overall holistic approach discussed at the NAE workshop. The following general themes were suggested at the workshop:

- the creation of pedagogical and cognitive models on how people learn STEM concepts, including how retention rates can be improved for women and students from underrepresented groups

- the creation of pedagogical and cognitive models for how IT-enabled resources influence STEM teaching and learning processes

- the creation of social models characterizing STEM faculty cultures and models for encouraging the adoption of new teaching and learning practices, as well as strategies for collaborative and teamwork

- the creation of economic models that support a sustainable ecology for IT-transformed teaching and learning

Recommendation 5. A national laboratory should be established to pilot test IT-enabled resources and practices for STEM educational applications. The laboratory should engage leading scholars in research on fundamental processes in IT-enabled STEM learning, provide a test-bed for interoperability, and provide a mechanism for documenting the impact of specific resources and practices on STEM learning. The laboratory should be developed under the leadership of an organizational champion and with the support of leading government agencies (e.g., National Science Foundation, National Institute of Standards and Technology, U.S. Department of Defense, and U.S. Department of Education)

Recommendation 6. A targeted research agenda should be established for the development of social, educational, and economic models for improved STEM learning in an IT-enabled context. Details of the research agenda should be generated through follow-on workshops and funded by agencies involved in the advancement of research on STEM education (e.g., National Science Foundation, National Institutes of Health, U.S. Department of Education, and leading private foundations).

Appendix A: Workshop Agenda

National Academy of Engineering
Workshop on Information Technology Based Educational Materials in Engineering Education
November 8, 2002

Eton Room - Henley Park Hotel
926 Massachusetts Avenue, NW
Washington, D.C.

AGENDA

8:00 a.m.	Continental Breakfast, Eton Room
8:30	Welcome, Introductions, and Review of the Agenda *William A. Wulf,* President, National Academy of Engineering *David A. Auston,* President, Kavli Institute *C. Sidney (Sid) Burrus,* Dean, Rice University, and Steering Committee Chair
9:00	Opening Statement from Steering Committee *Sid Burrus*
9:15	Panel Topics Issues in Architecture *M. S. Vijay Kumar,* Massachusetts Institute of Technology *Ed Walker,* IMS Global Learning Consortium Issues in Tools and Technology *Michael Kohlhase,* Carnegie Mellon University *Richard Baraniuk,* Rice University
10:00	Break
10:15	Panel Topics (con't) Issues in Content and Pedagogy *Donald Falkenburg*, Wayne State University *Alice Agogino*, University of California-Berkeley *Kurt Gramoll,* Oklahoma University Organizational, Cultural, and Legal Issues *Sid Burrus, Rice University* *Marietta Baba*, Michigan State University *Joel Smith*, Carnegie Mellon University

Workshop on Information Technology Based Educational Materials in Engineering Education
November 8, 2002

AGENDA (continued)

11:00	Open Discussion Identify Priorities for Establishing a National Strategy Identify Challenges and Barriers
12:00 p.m.	Lunch, Eton Room
1:00	Breakout Discussions Issues in Architecture Issues in Tools and Technology Issues in Content and Pedagogy Issues in Organizational, Cultural, and Legal Issues
2:30	Break
2:45	Reports from Breakout Teams and Open Discussion
4:00	Wrap-Up
4:30	Adjourn

APPENDIX B: WORKSHOP ROSTER

National Academy of Engineering

Workshop on Information Technology Based Educational Materials

Steering Committee

C. Sidney Burrus, *Chair*
Maxfield and Oshman Professor of Electrical and Computer Engineering and Dean
George E. Brown School of Engineering
Rice University

Donald Falkenburg
Director
Greenfield Coalition for New Manufacturing Education at Wayne State University

Michael Kohlhase
Adjunct Associate Professor
School of Computer Science
Carnegie Mellon University

M.S. Vijay Kumar
Assistant Provost and Director of Academic Computing
Massachusetts Institute of Technology

Project Sponsors

David Auston
President
Kavli Institute

Wm. A. Wulf
President
National Academy of Engineering

Invited Workshop Participants

Harold (Hal) Abelson
Professor
Electrical Engineering and Computer Science
Massachusetts Institute of Technology

Alice M. Agogino
Roscoe and Elizabeth Hughes Chair of Mechanical Engineering
University of California, Berkeley

Invited Workshop Participants (continued)

Marietta Baba
Dean and Professor
College of Social Science
Michigan State University

John Bailey
Director of Technology
U.S. Department of Education

Richard G. Baraniuk
Professor
Electrical and Computer Engineering Department
Rice University

Mariann D. Banfield
Webmaster
Program and Policy Studies Services
Office of the Under Secretary
U.S. Department of Education

Karen Billings
Vice President
Education Division
Software & Information Industry Association (SIIA)

Robert Black
Deputy Director and
Publications and Marketing Manager
American Society for Engineering Education

Sheri Brodeur
University Programs Manager
Hewlett-Packard Company

Ann Q. Gates
Associate Professor
Department of Computer Science
University of Texas at El Paso

Kurt Gramoll
Robert Hughes Centennial Professor of Engineering
Director of the Engineering Media Laboratory
University of Oklahoma

Joseph Hardin
Deputy Director of the Media Union and
Director of Systems Development and Operations
School of Information
University of Michigan

Frank Huband
Executive Director
American Society for Engineering Education

Christopher Israel
Deputy Assistant Secretary for Technology Policy
U.S. Department of Commerce

Bruce M. Kramer
Division Director
Division of Engineering Education and Centers
National Science Foundation

Invited Workshop Participants (continued)

Herbert Levitan
Section Head
Education and Human Resources/Division of Undergraduate Education
National Science Foundation

James H. McClellan
Byers Professor in Digital Signal Processing
Electrical and Computer Engineering Department
Georgia Institute of Technology

Jack McGourty
Associate Dean of Institutional Research
Fu Foundation School of Engineering and Applied Science
Columbia University

William C. Salmon
Secretary/Treasurer
Council of Academies of Engineering and Technological Sciences

Joel Smith
Vice Provost and Chief Information Officer
Computing Services
Carnegie Mellon University

Edward C.T. Walker
Chief Executive Officer
IMS Global Learning Consortium, Inc.

Jack M. Wilson
Chief Executive Officer
UMassOnline

Robert A. Wisher
Director of the Advanced Distributed Learning Initiative
U.S. Army Research Institute

NAE Staff

Matthew Caia, Senior Project Assistant
Lance Davis, Executive Officer
Katharine Gramling, Research Associate
Patricia Mead, Senior Program Officer
Proctor Reid, Associate Director, Program Office

APPENDIX C: SUMMARY NOTES FROM WORKSHOP BREAKOUT SESSIONS

Working Group on Architecture Issues

After sharing their thoughts and impressions of several initiatives, participants in the architecture working group developed a proposal for assembling a national laboratory to help individuals and groups develop interoperable systems. The laboratory would also raise awareness of IT-enabled educational tools and promote their adoption.

Other thoughts that emerged from the discussions are listed below:

- Assemble (not "build") a laboratory modeled after the FermiLab or CERN. The new lab should be a tool for doing science and engineering, not a sandbox.
- The lab and plans for its activities should be based on current projects and available tools, that are making existing tools and content work. In the beginning, the lab should not be for technology creation.
- As new tools are developed, they should be demonstrated in the lab with other tools to ensure interoperability, etc. The lab may be modified as necessary.
- Exemplary learning activities involving IT tools and content should be discovered or developed in the lab. These could demonstrate applied pedagogy (e.g., a case-based learning activity in a subject such as law, medicine, business, or engineering.)

The objectives of the lab should be:

- Open everything.
- Push the limits of interoperability.
- Promote adoption through examples and demonstrations.

Although everyone agreed that the lab, or something like it, will be important to begin integrating innovations, the state of readiness for a lab will depend on several things:

- the availability of lab components, tools, and content (including people and "documentation")
- the level of investment and commitment of resources
- the level of participation by institutions and individuals

The group identified several critical issues related to the creation of a lab of this kind: (1) offering different kinds of incentives; and, (2) lowering the barriers to participation. The lab should be a nonproprietary effort, but commercial participation in the lab's activities will be important.

Working Group on Tools and Technology Issues

Participants in the technology and tools working group developed several recommendations regarding IT-enabled educational materials:

- Open and content-oriented formats are preferable to proprietary formats for source documents. (Source documents are the primary storage and archive forms of documents; other formats can be derived from these by translation and aggregation.)
- Some domains have well developed, open-content mark-up formats e.g., MathML and OpenMath for mathematics and ChemML for chemistry.) Some disciplines do not have open-content formats, (e.g., computer science has no language-independent code markup format). The missing formats and a general knowledge/context representation format should be developed.
- Define the relationship between object/domain/context/metadata. Determine the level at which metadata are useful and in which contexts various levels of granularity of metadata annotation are needed.
- Develop tools to author and translate materials in source and target formats, including all four categories of data.
- Identify the user communities and develop adoption plans for whatever tools and formats are ready. Get institutional commitments. (An analogy for this: AMS and AIP endorsed TeX very early on, considerably easing the adoption path).
- Adapt techniques that (also) deal with administrative nuisances like accreditation.
- Develop and fund demonstration projects for exemplary value-added educational services.
- Concentrate on enabling technologies and building communities rather than large-scale systems.

Participants agreed that issues related to tools and technology in IT-enabled education could not be adequately addressed without also considering architecture, content, pedagogy, and the cultural environment.

Working Group on Content and Pedagogy Issues

Discussions in the content and pedagogy working group were organized around three issues:

1. What factors in the current state of practice impede the reuse of IT-enabled learning resources?
2. What environment do we need to do things right?
3. What steps should we take to achieve the environment that supports our needs?

Factors that Impede Reuse

- The learning resources developed by faculty are usually created for *their* use in *their* classrooms. The team described them as "lacking training wheels". They provide no instructor guide and no embedded advice describing how these resources should be used to meet instructional objectives.
- Modifying or adapting materials may require a level of effort that exceeds the perceived benefit to another faculty member.
- Faculty organize their coverage of material in different ways. Changing the modularity or guided sequencing of the learning process may change underlying learning pedagogy.
- If a faculty member finds an interesting learning resource on the web, he or she rarely finds user evaluations. As someone in the group put it, "It would be great if my colleagues indicated that this is so effective that I conclude, *I can't afford not to use this resource!*" We need filtering mechanisms to describe the instructional context of the resource and its effectiveness in that context.
- There is scant use of metadata to describe shared learning resources. When it exists, the vocabulary used by the author may not conform to emerging standards. The Learning Object Model (LOM) defined in the standards documents is so complex that most faculty won't even begin to use these important descriptors. What are the essential fields that all sharable learning resources must include? There is no centralized service (clearing house) to support the effective use of metadata.
- Achieving interoperability is a multidimensional task that extends beyond technical issues. If we do not express objectives in concise, performance-based terms, and if we do not have a common framework for documenting assessment data, we cannot achieve interoperability for users of sharable learning resources.

The Right Environment

- We will make no progress unless the academic community encourages faculty to work cooperatively and selflessly. This would mean a radical change in the existing academic culture! It would recognize the value of building on work by others and adapting and adopting would be encouraged. Institutions would commit resources to support teaching.
- Faculty would be rewarded for creating innovative teaching/learning materials, which would be treated as the "scholarship of learning" and would be of equal value with traditional research.
- The university must create a *sustainable* organization that provides the technical support necessary to use/create learning objects.
- Materials will be developed in such a way that they can be easily repackaged and reconfigured for a new academic context or for reuse to support training and

lifelong learning in industry.

Bridging the Gap

The breakout group agreed that we do not know how to create an ideal environment that supports sharability. We must focus our research on the problems and approaches to achieving the promise of IT-enabled learning. The breakout group recommended the establishment of a test-bed, which would support scholarship on IT-enabled learning in real-world learning/teaching environments:

- We must understand communities of learning (determining what do we know now and what we need to know)?
- The test-bed should include evaluations of content and pedagogy.
- Activities and results should be shared and coordinated with other activities supporting IT-enabled learning (e.g. National Science Foundation Digital Library).
- We should adapt existing principles and approaches to software engineering, portfolio management, and customer-driven design.
- Rather than building a test-bed from scratch, we should build upon, and involve, organizations currently involved in related efforts.

Our ultimate success will depend on human and organizational issues. We must create incentives/mandates for designing for share-ability. The entire community—teachers, learners, and support personnel—must be involved.

Working Group on Organizational, Cultural, and Legal Issues

Participants in the organizational, cultural, and legal issues working group agreed that before a strategy to achieve our vision can be formulated, we must identify, categorize, and articulate the perceived impediments. Another way to state this is to ask what resources (financial, technical, cultural, theoretical, and legal) we would need to realize our vision. These following impediments were identified

- The absence of strong institutional and collegial commitment will make it very difficult to achieve the vision. This entire university community (e.g., board, administration, faculty, staff, and students) must "buy in" to the idea and provide the hardware, software, staff, time, and commitment to realize the potential of IT-based education.
- We do not currently have user-friendly tools for authoring, modifying, maintaining, and using information content. These tools must also support multi-authoring and sharing.
- The current projects often have incompatible formats and protocols that are too "human"-oriented. Computers and communication systems, as well as humans, must be able to "understand" the information.

- We do not have a culture of community authorship. The software community has developed the beginnings of such a culture with the open-source movement, but the education community still has a single-author, single-instructor culture.
- Few learning models are based on cognitive theory that incorporates modern IT. Without good models and agreed-upon criteria, it is difficult to evaluate a teaching or learning system of any kind.
- Even if we had easy-to-use, effective, efficient systems and tools, we would still have to convince instructors and students to use them. Adoption is often a serious problem, partly because it is not always clear that there is a significant benefit, and partly because of the traditional resistance to change. Students expect to learn the way they have always learned and faculty expect to teach the way they have always taught. A minority are "early adopters," but most are not and must be convinced to use something new.
- The cultural attitudes about ownership of, credit for, and compensation for creating and using shared, technology-enhanced materials are based on the traditional single-author model. Mechanisms for awarding tenure, assigning salary increases, and giving recognition and rewards must be changed.
- A very serious impediment to the implementation of shared material systems is our traditional copyright laws and the way they are used by authors and publishers. A system being developed by the Creative Commons organization will be essential for progress.
- The wide diversity of our institutions, faculty, and students present a great challenge. We must involve research universities and community colleges, K-12 schools, institutions of higher education, as well as continuing education and industrial training programs. We must also begin to collaborate with other nations, including other English-speaking countries. The systems we develop must address different learning styles, backgrounds, and preparation levels of the students, which we currently address by having a variety of schools. The global nature of our vision will present a new challenge.
- The current communities of authors, teachers, and students do not significantly overlap. The new model will have much more overlap, with students involved in both teaching and authoring, teachers involved in authoring, and authors becoming more aware of teaching and learning.
- Currently there is not nearly enough available content for most of the systems we envisage. There are plenty of books and journal articles, but they are not in a format for shared systems, and, under current copyright agreements, they cannot be shared.

In trying to realize a vision or to convince a community to change, there is always a danger of "overselling" or promising more than can be delivered. We must be very careful that we have working systems before we start promising things we may only be able to deliver sometime in the future. The artificial intelligence community learned this lesson the hard way.

APPENDIX D: GLOSSARY

ChemML

ChemML is an application that uses XML (or XHTML) allowing developers to use and present science content on the Web and in various other applications. Some additional details can be found at <*http://ncam.wgbh.org/salt/guidelines/sec11.html*>.

Connexions

This is a collaborative, community-driven approach to authoring, teaching, and learning developed at Rice University. Connexions seeks to provide high-quality educational content to anyone in the world. More details can be accessed at <*http://cnx.rice.edu/*>.

Creative Commons

Creative Commons is a non-profit corporation offering the public a set of copyright licenses free of charge. This group is also working to build an "intellectual property conservancy" that will protect works of special public value from exclusionary private ownership. Details can be found at <*http://www.creativecommons.org/*>.

Dspace

Dspace is an open source software platform that allows institutions to capture, preserve, and distribute digital information over the Internet. Details on the initiative can be found at <*http://www.dspace.org*>.

IEEE

Institute of Electrical and Electronics Engineers, Incorporated is a professional society of electrical, electronic, and computer engineers and technicians. Details about the organization can be found at <*http://www.ieee.org/*>.

IETF

The Internet Engineering Task Force is an international community of network designers, operators, vendors, and researchers concerned with the operation and evolution of the Internet. Details about this organization can be found at <*http://www.ietf.org/*>.

IMS

Instructional Management Systems Global Learning Consortium, Inc. in an organization that develops and promotes open specifications to facilitate online distributed learning activities. Additional details can be found at <*http://www.imsglobal.org/*>.

ISO

International Organization for Standardization. Details can be found at <*http://www.iso.ch/*>

Learning Object

Computer routine that performs an educational function or service.

MathML

MathML is an application of XML that facilitates the use and re-use of mathematical and scientific content on the Web, and in other applications including print typesetting and voice synthesis. Details can be found at <*http://www.w3.org/Math/*>.

MERLOT

Multimedia Educational Resource for Learning and Online Teaching (MERLOT) is a free resource designed primarily for faculty and students of higher education. More details can be found at <*http://www.merlot.org/Home.po*>.

Metadata

Metadata is data that describes other data. The term is often used to refer to any items that describe data, like the contents of HTML meta tags or title fields.

NSDL

National Science, Mathematics, Engineering, and Technology Education Digital Library, an NSF initiative to establish a digitally based repository of educational materials that can be shared and utilized by faculty and other educators.

OCW

Open courseware (OCW) is a large-scale, web-based electronic publishing initiative to provide free course materials for educators and to encourage standards for courseware published on the Internet. More details on the initiative can be found at <*http://www.ocw.mit.edu*>.

OKI

The Open Knowledge Initiative is developing open architectural specifications to support the development of educational software. More details are available at <*http://web.mit.edu/oki/*>.

SCORM

Sharable Content Object Reference Model defines a structure for combining content for Web-based learning.

Semantic model

A design structure for organizing material based on content rather than presentation.

Semantic Web

The W3C in collaboration with many researchers and industrial partners is developing this abstract representation of data on the World Wide Web. It is based on content-oriented standards. More details can be found at <*http://www.w3.org/2001/sw/*>.

SMETE

SMETE is an acronym for science, mathematics, engineering, and technology education. The SMETE Open Federation in an organization dedicated to promoting the teaching and learning of science, mathematics, engineering and technology at all levels. More details about the Federation are available at <*http://www.smete.org/*>.

WebDav

WebDAV stands for 'Web-based Distributed Authoring and Versioning' which extends the rules of the current HTTP standard to allow multiple users to edit source material through the Internet. More details are available on the WebDAV Resource page <*http://www.webdav.org/*>.

XML

XML is an acronym for eXtensible Markup Language, a flexible text format derived from SGML (ISO 8879), and originally designed to meet the challenges of large-scale electronic publishing. XML is also playing an increasingly important role in the exchange of a wide variety of data on the Web and elsewhere.

XSLT

XSLT is an acronym for eXtensible Stylesheet Language for Transformations, a language for transforming XML documents into other XML documents.

APPENDIX E: STEERING COMMITTEE BIOGRAPHIES

C. Sidney Burrus received his Ph.D. from Stanford University in 1965, after which he joined the faculty at Rice University, where he is now the Maxfield and Oshman Professor of Electrical and Computer Engineering (ECE) and dean of the George R. Brown School of Engineering. From 1984 to 1992, he was chairman of the Electrical and Computer Engineering Department at Rice, and from 1992 to 1998, he was director of the Computer and Information Technology Institute (CITI). In 1975—5-1976 and again in 1979—9-1980, he was a guest professor at the Universitäaet Erlangen-Nuernberg, Germany; during the academic year 1989—9-1990, he was a visiting professor in the Electrical Engineering and Computer Science Department at Massachusetts Institute of Technology. Dr. Burrus received teaching awards at Rice in 1969, 1974, 1975, 1976, 1980, and 1989, an IEEE S-ASSP Senior Award in 1974, a Senior Alexander von Humboldt Award in 1975, and a Senior Fulbright Fellowship in 1979. He was elected a fellow of the IEEE in 1981 and a recipient of the IEEE S-ASSP Technical Achievement Award in 1986. From 1989 to 1992, he was a distinguished lecturer for the Signal Processing Society and for the Circuits and Systems Society. He was awarded the IEEE S-SP Society Award in 1994 and the Millennium Medal in 2000. Dr. Burrus served on the IEEE Signal Processing Society ADCOM(spell out) Advisory Committee for three years and has coauthored five books on digital signal processing.

Donald Falkenburg, the director of the Greenfield Coalition for New Manufacturing Education, was previously professor and chair of the Department of Industrial and Mechanical Engineering at Wayne State University in Detroit. Members of the Greenfield Coalition include Focus: HOPE, six universities, several companies, and an engineering society, all of which have representatives on the coalition's Board of Directors and other boards. The coalition has its own educational campus, which includes an advanced manufacturing facility, located in the community it serves. The program and facility combine theory and application so that students—called candidates—learn engineering fundamentals while they work under contract to major manufacturing companies to design and build products. Dr. Falkenburg earned his B.S. and M.S. in mechanical engineering from Clarkson University and his Ph.D. in systems engineering from Case Western Reserve University. He joined the faculty of the College of Engineering at Wayne State University in 1989 and became director of the Greenfield Coalition in 1999.

Michael Kolhase received his Ph.D. from the Universitäat des Saarlandes in Germany in 1994, after which he received a Dissertation Prize of the Working Group of German Artificial Intelligence Institutes. Since 2000, he has been a visiting researcher at the School of Computer Science at Carnegie Mellon University, funded by a five-year Heisenberg stipend from the Deutsche Forschungsgemeinschaft (DFG). Dr. Kolhase, on leave from his position as associate professor in the Department of Computer Science, Universität des Saarlandes University, is a principle investigator for the CCAPS Group, which is designing and implementing a system to store, organize, index, and make searchable, course content and preserve that content reliably over long periods of time. Dr. Kolhase's research interests include higher order unification and theorem proving, logics and calculi for partial functions, deduction systems, and natural language semantics.

M.S. Vijay Kumar, assistant provost and director of academic computing at Massachusetts Institute of Technology (MIT), has greatly influenced MIT's strategic focus on educational technology and promoted the effective integration of information technology into MIT education. As director of the Information Systems Academic Computing Practice and a member of its leadership team, Dr. Kumar provides leadership and coordination for academic computing activities and services that support the use of information technology in MIT's educational programs. He also leads MIT's Academic Media Production Services (AMPS), which brings together MIT Video Productions, Streaming Media Services, and the Educational Media Creation Center in support of MIT initiatives, such as SMA (the Singapore MIT Alliance), CMI (the Cambridge MIT Institute) and OCW (Open Courseware). Among his many other activities, Dr. Kumar is the principal investigator of the Open Knowledge Initiative (OKI), a collaborative effort supported by the Andrew J. Mellon Foundation to develop an open-source, open architecture for internet-based educational applications. He received his Ed. D. from University of Massachusetts, Amherst, and his M.S. in industrial management and B. Tech. in chemical engineering from the Indian Institute of Technology, Madras, India.