Connexions[SM]

Sharing Knowledge and Building Communities

Rice University *
cnx.rice.edu

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Overview

Connexions[SM] is a community-driven approach to authoring, teaching, and learning that conveys the dynamic continuum of knowledge. Available free of charge to anyone and under open content and open source licenses, Connexions hosts a Content Commons of electronic course material that is adaptable to a wide range of learning styles and encourages students to explore the links among concepts, courses, and disciplines. Connexions is fostering worldwide, cross-institutional communities of authors, instructors, and students, who collaborate on the creation of information modules, courses, and curricula. We believe that the ideas and philosophy embodied by Connexions have the potential to change the very nature of teaching and learning, producing a dynamic, interconnected educational environment that is pedagogically sound, both time and cost efficient, and fun.

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* Contacts: Richard Baraniuk (richb@rice.edu), Geneva Henry (ghenry@rice.edu), and Connexions (cnx@rice.edu)

1. Executive Summary

There is a great need for a way to develop and deliver quality, up-to-date educational materials able to convey to all learners that knowledge is a dynamic continuum that stretches across disciplines and is constantly redrawing educational boundaries. Recent technological advances offer a unique opportunity to embrace this exciting concept, igniting in students a love for learning while offering a novel collaborative model for creating and refining knowledge.

Disconnects in the knowledge continuum – A learner's perspective

One can think of the entire base of knowledge as a vast *continuum*, a flow of interrelated concepts. However, knowledge is traditionally transmitted to students in a series of formalized steps that interrupts the flow and breaks the natural links among concepts. Moreover, knowledge is often packaged and delivered in ways that fail to take into account students' learning styles and natural curiosity.

Imagine, for example, a typical student. He or she enters kindergarten and gradually progresses up the rungs of the educational system in a series of grades. If she is in fifth grade, then she dips into the "knowledge flow" at the proscribed "fifth grade level," no matter if she wishes to revisit "fourth grade level" concepts or explore new "sixth grade level" concepts. If he is a college freshman, then he is usually relegated to a set series of entry-level courses. Even if he has been able to dip into the knowledge flow at the college level from an earlier grade (such as through advanced placement courses), his existing knowledge base is often ignored at the next step on the ladder. Beyond our system of free public schooling, in addition, those who wish to access the knowledge flow must pay for the privilege. For many people, even those who climb as far as a graduate degree, the knowledge flow is inaccessible once they reach the end of the ladder; there is no mechanism by which an individual can easily access the latest additions and refinements to the knowledge continuum.

This interruption of the knowledge flow is exacerbated by several additional factors. Even within one grade — one rung on the ladder — concepts are transmitted in discrete units (for example, science or history), and very little is made of the potential connections between them, not to mention connections to areas that, while of great interest to the learner, are not part of the prepared lesson plan or syllabus. Students from kindergarten to college are typically taught "off the rack" content from a fixed syllabus and textbook that together cater largely to a single learning style. Further, the way concepts are delivered suggests to a learner that the information is immutable and therefore complete. As a student progresses through this system, she experiences several major transitions, from teacher to teacher and from school to school. Moreover, students are often placed in a passive role: the system offers little opportunity for them to contribute their own ideas, or to discover their own links among the concepts of the knowledge continuum.

Taken as a whole, the present system is ineffective: it transmits knowledge in a manner that is largely divorced from the learner's interests and needs. This leads to students who are unmotivated, bored, and who fail to see the importance of mastering key concepts, because they fail to grasp the very existence of the knowledge continuum.

Inefficient methods of knowledge development and transmission – An educator's perspective

The knowledge continuum, that broad flow of interrelated concepts, is constantly in flux. New ideas and concepts are added, existing information is refined, and outdated information is removed. The process by which this takes place includes, for example, the publication in refereed journals of research data and the independent verification of the initial research results. In other fields, for example the humanities, new ideas may be advanced through their publication in books. The scholars behind this work usually toil in solitude or in small groups. The refinement of these ideas, which occurs once they are subject to scrutiny by others, takes place once the material enters the flow of the knowledge mainstream.

The traditional method of transmitting this information — textbook publishing — is inefficient. In contrast to the rate at which the knowledge continuum changes, it is a glacial process. The dynamics of the system are lost; students receive what is essentially a still photograph of the continuum at a given point in time. Textbook authors must devote several years to writing their books, and then their work is subject to editorial review. Finally, their books enter the printing and marketing cycle. This is a substantial time commitment for college professors. Thus, textbooks are, almost by definition, stale even at the date of their publication. Knowledge that is evolving at a rapid pace, such as in computer science, environmental science, bioinformatics, and medicine, can never be captured by this traditional delivery method.

Not only is the transmission process slow, it is exclusive. Only a very small percentage of faculty are willing to devote the time it takes to go through this process. It also virtually shuts out educators who are working at either ends of the educational ladder: those working with pre-college students and life-long learners. This has the immediate side-effect of severely limiting diversity of opinion.

In addition to portraying the continuum as falsely static and limited in scope, this transmission process also fails to provide a feedback loop on what information is readily absorbed by learners, considering that different learners may have different learning styles. If a textbook portrays information in a fashion that is difficult for a student to comprehend, then his individual teacher may supplement the material or devise an alternative method for delivering the information. But these adaptations are rarely, if ever, used to improve the textbook itself. Certainly they are not available to help other teachers in other classrooms alter the material for their students.

The Connexions project

The past five years have witnessed the emergence of a growing movement of concerned educators and scientists who aim to open up access to the world's knowledge resources. Inspired by parallel developments in the open-source software world (the Linux operating system, for example), this movement seeks to provide free access to quality teaching materials that are amenable to customization and personalization to match local contexts (language, level, etc.). Moreover, this movement seeks to link and empower local educators in a global knowledge community that can efficiently and benefit and propagate the materials.

The *Connexions* project was launched at Rice University in 1999 to challenge both current modes of teaching and learning as well as how knowledge is developed and shared [1]. Befitting its name, Connexions has two primary goals:

- To convey the *interconnected nature of knowledge* across disciplines, courses, and curricula;
- To move away from a centralized, solitary authoring, publishing, and learning process to one based on *connecting people into global learning communities* that *share knowledge*.

A fundamental aspect of Connexions is an emphasis on *free content* that is *open-licensed* to facilitate sharing, easy re-use, and easy re-contextualization.[1] In combination with powerful software tools, Connexions gives learners of any age free access to knowledge materials that can be readily manipulated to suit their individual learning styles as they explore links among concepts. The free software tools also foster the development, manipulation, and continuous refinement of the materials by diverse communities of authors and teachers.

Starting with an initial proof of concept, Connexions has been under intense development and is beginning to attract the attention of a growing number of concerned educators worldwide. Its hallmarks include (see Figure 1):

- A *Content Commons* of diverse educational materials spanning the knowledge continuum, which are modularized for easy reuse and available free-of-charge to anyone in the world;
- *Visualization and navigation* of the "Connexions" among concepts, courses, and curricula;
- High-quality materials, thanks to an iterative development process and an inherent *quality assessment* mechanism;
- *Rapid, collaborative authoring* of the materials by global communities of authors;
- Flexible, dynamic construction of an infinite variety of *customized courses and curricula*, enabled by a coherent format (XML) and delivered in a variety of forms, from Web pages to e-books to paper texts.
- *Multilanguage capability* to support diverse audiences;
- A coherent intellectual property (IP) framework based on the *Creative Commons* open-content licenses [2].

[1] An open license allows anyone to read, copy, modify, and redistribute the work (software or content) as long as they permit others to do the same.

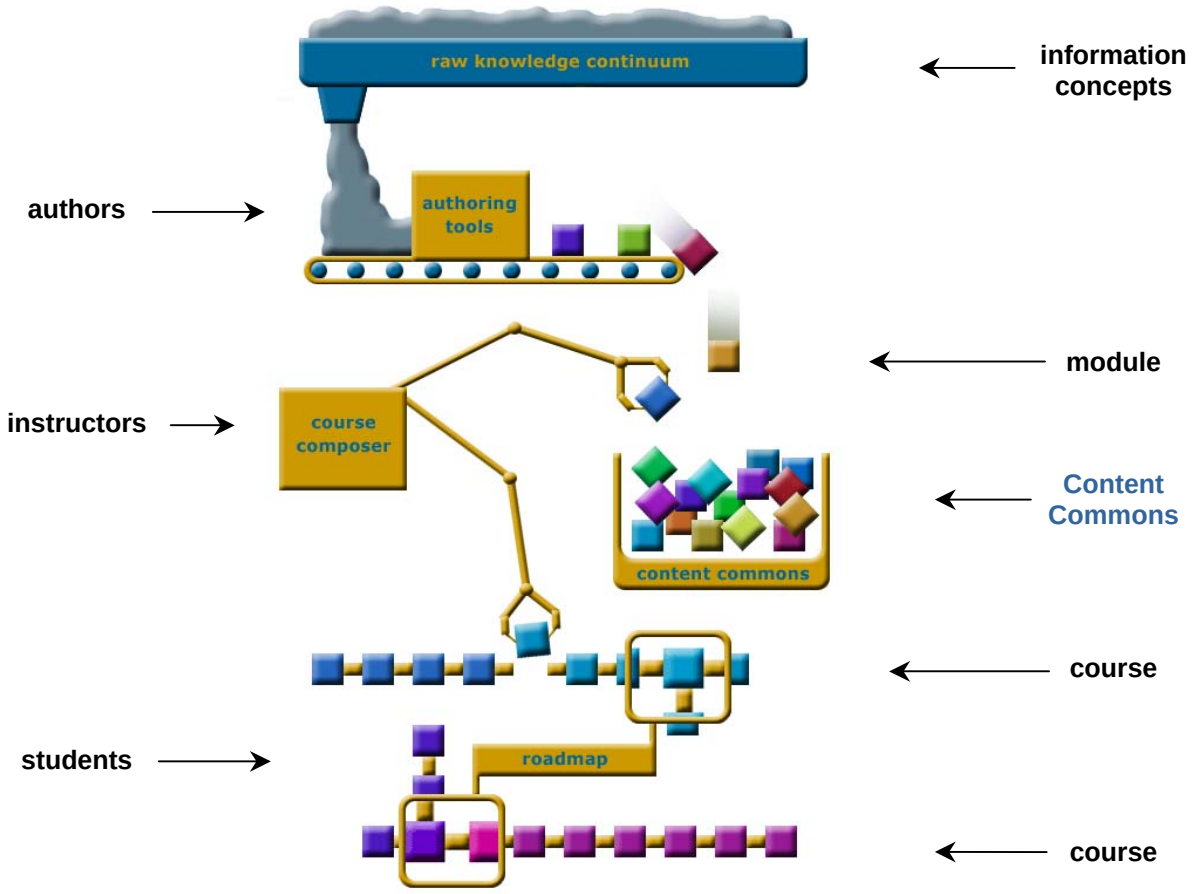

Figure 1: Connexions as a dynamic "knowledge factory."

Benefits of Connexions

Connexions offers a number of benefits over the traditional modes of knowledge development and delivery:

Collaborative and Inclusive: Connexions fosters the development of a diverse, worldwide community of authors who work collaboratively to create, expand, review, and maintain the content commons. Inherently inclusive, this community can include a vast cross-section of university faculty, industry professionals, K-12 teachers, and even talented students.

Dynamic and Innovative: The ability of a vast community of authors to readily and dynamically access and update information is especially important in rapidly changing fields. Moreover, the free materials provide fuel for innovation, since authors can build on and refine anything in the commons.

High quality: The continual refinement of modules and courses, combined with a combination of peer-review and pride-of-authorship (as in the Linux open source development model), results in

high quality materials. Further, the Connexions architecture is compatible with any possible combination of third-party editorial systems. See more about lenses under the topic "Post-publication review" on page 10 of this document.

Holistic: By linking a great diversity of ideas, ideologies, and pedagogical methods across concepts, courses, and even disciplines, Connexions provides students with a "big picture" vision that no traditional course or textbook can provide. The question "Why do I have to study calculus when I'm really interested in biology?" becomes clearer as a student explores the concepts, enabling "aha!" moments at an earlier age. This is especially critical in the areas where undergraduates now often choose another discipline because the usefulness of the introductory courses in these fields is not apparent. Connexions can also help instructors build curricula by bringing into focus the gaps between courses. Finally, Connexions allows learners to freely explore the larger content commons, while learning at an appropriate rate for them.

Coherent and Persistent: Because all content modules are encoded in a single coherent format (XML), they can be woven together seamlessly and presented in myriad different output formats, from Web pages to e-books to print. The reusability of Connexions modules lies in stark contrast to the hodgepodge of loosely connected HTML, PostScript, PDF, Microsoft Word, and Power Point documents comprising the world's many educational Web sites. In contrast to other Web-based educational projects based on hyperlinked indexes, which are often plagued by broken links, Connexions content is persistent — it will always be there.

Efficient: Breaking course materials into discrete modules drastically reduces the time commitment required of authors and instructors, who can now write a high-quality module or weave a customized course in an evening or weekend. A vastly expanded community of authors will result. Furthermore, once contributed to the commons, a module can be reused in myriad courses and rapidly adapted to new settings.

Scalable: Connexions materials can be developed across many fields of study, and they can be easily adapted to, and developed in, a variety of educational environments, including K-12, college, continuing, distance, self-paced, and corporate education. Modules can also be developed to cover a wide range of learning styles and can be translated into many different languages.

Three-phase development plan

Our goal is to take Connexions to critical mass on a global scale. We plan Connexions' development as a 3-phase process:

Phase 1 – Proof of concept (2000-2004): After four years in development, Connexions officially launched its portal in February 2004 with over 1700 modules and 35 courses and a fully documented toolset for navigation (Roadmap), annotation, and publication [1]. Web hits on the Content Commons increased over 20 fold from Q4 2002 to Q4 2003, to over 250,000 per day.

Phase 2 – Buildup (2004-2007): Over the next three years, we will be greatly expanding the Content Commons, extending its depth and breadth with educational materials from authors around the world. An easy-to-use enhanced toolset will promote scaling to large numbers of

users. Release 2.0, planned for summer 2004, will feature a free, open source XML/MathML editor and multi-language capability. Release 3.0 will enable distributed repositories for the Content Commons, multi-licenses, and lenses to focus access.

Phase 3 – Sustainability: (2007+): We plan to establish a sustainable maintenance infrastructure for Connexions under a non-profit "dot org" entity that will allow Connexions to be "owned" by the communities it supports.

Funding for Connexions has come from Rice University, including three trustees and two friends of Rice, the William and Flora Hewlett Foundation, the CLASS Foundation, and the National Science Foundation.

The balance of this document contains an overview of the Connexions software architecture, our current content projects, quality control mechanisms, and our future plans.

2. Connexions Architecture and Tools

The Connexions architecture and software tools have been designed to support the development, management, and exploitation of the content commons [3-6]. In a nutshell, the Connexions tools can be introduced using the "factory" analogy of Figure 1. A global community of authors continuously converts "raw knowledge" from the continuum into small, self-contained *modules* of information, the equivalent of a page or two in a textbook. Modules can be imagined as special Web pages with hyperlinks pointing to prerequisites, applications, and supplementary material. Modules are placed in the *Content Commons* (a database repository) to be used, reused, updated, and adapted. Instructors use a *Course Composer* software tool to weave modules into *customized courses* that can be placed on the Web, presented in class, or printed as a paper text. Students and other learners access Web courses or the Content Commons directly, using special *visualization and navigational tools* designed to highlight the non-linear "Connexions" among concepts both within the same course and across courses and disciplines. To promote the broadest impact, freest exchange of ideas, and most rapid and dynamic development, all materials are available free-of-charge under an open content license analogous to the open source license of the Linux operating system. Likewise, all software tools are provided under an open source license. The result is a coherent system for course development, organization, and delivery that mutually benefits students, instructors, and authors.

The Connexions architecture and tools sketched in Figure 2 echo the factory analogy of Figure 1. The tools are designed to be flexible, scalable, and easy to use for authors, instructors, and students alike [5, 6]. Beta versions of the tools were used at Rice University and by faculty at several other institutions before the 1.0 launch of Connexions. The 1.0 launch included full documentation on the Connexions tools.

Content modules and semantic markup: Authors compose modules using the extensible markup language (XML) [7], which allows Connexions to exhibit the links among related modules, display images and videos, launch interactive applets, support myriad output formats, enable powerful search mechanisms, and display and print clear and attractive mathematics (using

MathML). XML extends the familiar HTML that forms the backbone of the World Wide Web. Connexions' specifically designed markup language for course content is called *CNXML*. Since XML encodes what the content *means* rather than how it should be *presented* (displayed),[2] modules are very flexible — the same CNXML source module can be displayed as an individual Web page, woven seamlessly into many different courses, converted to LaTeX, PostScript, or PDF for printing, or even processed through a speech synthesizer to read material to the blind. The ultimate presentation of a module depends on a *style sheet* that is chosen by the end-user and not fixed a priori by the author.

Semantic tagging promotes sharing, repurposing, and aggregation of modules into larger units. We are creating "XML Crosswalks" across disciplines and other XML languages, including MathML, OpenMath, CodeML, ChemML, TEI, IMS, and SCORM. These crosswalks will allow communities of authors to easily create and share educational materials that retain their semantic meaning, independent of medium or platform.

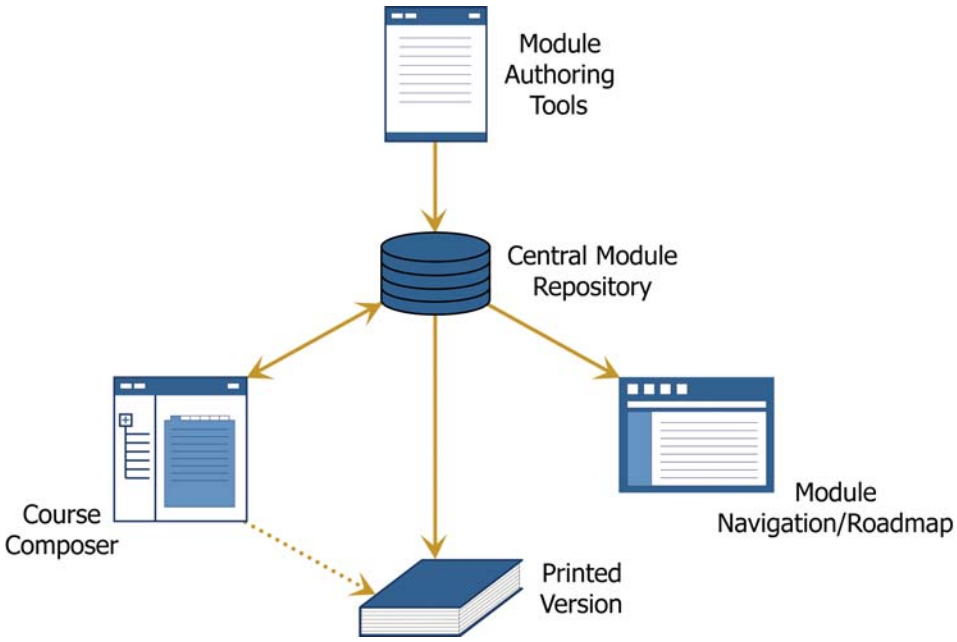

Figure 2: Connexions' architecture and tools.

[2] HTML, on the contrary, mixes content and presentation information. For example, the HTML `<bold>` tag finds use around both the journal volume number in an academic citation (as in " SIAM Review, **34**(7)") and shouted words in a theatre piece (as in "**Turn that music down!**"). Clearly the HTML `<bold>` tag carries much presentation and little content information. XML separates content and presentation [3]. In XML, we can define a `<volumeNumber>` tag for journal citations and a `<shout>` tag for plays. Furthermore, the end-user can decide, using a "style sheet" how a `<shout>` item should be displayed. Some users may want to italicize shouting, as in "*Turn that music down!*". Similarly, for mathematics, content MathML allows us to encode that the symbol "*x(t)*" means "the function of the variable" rather than the letter "x" followed by the symbol ")", the letter "t", and the symbol ")", which is how *x(t)* would be encoded in LaTeX, Word, or PowerPoint. Because of this extra meaning information, content MathML formulas can be pasted directly into Mathematica and calculations performed with them.

Authoring tools: Any of a variety of XML editors can be used to generate new modules. Content conversion from standard formats (such as LaTeX, Word, or Power Point) is complicated by the fact that these formats are primarily presentation-based rather than content-based. Consequently, developing an easy-to-use authoring suite is now our software team's highest priority (a free open source XML editor is planned for Release 2.0 in summer 2004). The Connexions authoring Web site enables authors to communicate with each other, collaborate on shared modules in ad hoc workgroups, and submit their work to the Content Commons.

Content Commons: The Content Commons stores the content modules and manages their access. At present, the Content Commons is a centralized storage system to simplify its maintainability, availability, and reliability; proxy cache servers will be used to improve access to frequently used modules. A distributed, potentially peer-to-peer repository is planned. Content CNXML modules are stored as text in a version control system (currently Concurrent Versioning System, or CVS) to maintain their complete revision history. Version control software is crucial to track changes to a module, to attribute who changed what, and to lock in a specific version for a given course so that it does not change from the instructor's intended use in their particular course. Metadata for each module are stored in a database for easy search and retrieval. The metadata include module title, authors, keywords, and the linking structure (which modules link to which other modules). The Dublin Core metadata standard is guiding the metadata defined for the project, with some additional elements added to meet the needs of Connexions.

Course Composer: This tool allows instructors to search the Content Commons for modules, group them into "chapters," sequence them into a course, and add customizing annotations ("margin notes") and segues from module to module. Instructors can also overlay new links between previously unlinked modules. The course path and materials can be stored on the Connexions Web site or a local Web server and presented through a Web browser. Alternatively, a linear PostScript or PDF version can be created for printing locally or spooling to an on-demand publisher such as Kinko's.

Roadmap: The Roadmap tool is a Web browser plug-in that guides students through each course, helps them visualize the non-linear Connexions among the concepts in different modules, courses, and curricula, and encourages them to explore related topics and then return easily to their course path. Students can make their own personal "margin note" annotations that will be available to them whenever and wherever they review the course materials. Connexions works with a range of browsers and on several platforms. For rapid prototyping, the Roadmap was developed for use with Mozilla, the open source Web browser that forms the core of Netscape 6 and 7. The full functionality of Roadmap is currently being migrated to Microsoft Internet Explorer.

Future planned tools will support discussion and collaboration, automatically discovering links among different modules (through usage patterns, for example), constructing concept maps, learning assessment, and testing. All Connexions software and tools are open source, free of charge, and currently available in the 1.0 release. More information is available at Connexions' Web site at cnx.rice.edu.

3. Connexions Content

The open content development model is the most radical aspect of Connexions, but it holds the key to populating the Content Commons with a critical mass of high-quality content. Those unfamiliar with the power of open development should read Eric Raymond's classic essay, "The Cathedral and the Bazaar" [8] to gain more insight into the benefits of developing content and software under open licenses.

Open content, community development

Rather than the traditional content development model of one author to one textbook, Connexions links worldwide communities of authors to collaboratively create, expand, revise, and maintain modules and courses. The result is a dynamic, up-to-date content base that makes the latest knowledge globally available. The professional integrity of authors and an inherent peer review system will ensure high quality, as described in more detail below.

In Connexions, authors retain the copyright on their materials but make them freely available under a *Creative Commons* open-content license [2]. This license shares the spirit of open source software licenses like the General Public License (GPL) and Berkeley Software Distribution (BSD) license but is expressly designed for content. The license allows anyone to copy, modify, and redistribute Connexions modules and courses as long as they attribute the original author(s). To take the guesswork out of what users can and cannot do with the content, we embed the license information directly into the XML source of each and every module and course.

Open development has the potential to be extremely cost-effective and time-efficient, since it leverages the efforts of a global community and allows each module and course to be reused in numerous different contexts. Connexions substantially lowers the barrier to entry into the author community. Since authors can now contribute a high-quality, high-impact module in an evening or weekend, many more college faculty, industry professionals, K-12 teachers, and even talented students will contribute materials. Consider this quote from an electrical engineering faculty member: "For years I have wanted to write a textbook, because I love to write about FFTs (Fast Fourier Transforms). However, any complete text in my field also has to cover *z*-transforms, on which I have no interest in writing." Connexions will allow this faculty member to contribute his FFT material and then weave a custom text for his course using contributions from other authors passionate about *Z*-transforms.

Open content development is not incompatible with commercial publishing. Indeed, high-quality but very low-cost textbooks are already printed and bound by Kinko's each semester for several courses at Rice University. And a new electrical engineering book by professor Alfred Hero from the University of Michigan will appear simultaneously as a traditional Cambridge University Press paper book and in Connexions for free.

We envision that, in the future, module usage history (the number of courses it appears in or the total number of visits, for example) and ratings (by external bodies, such as the American Physical Society, Institute of Electrical and Electronic Engineers or American Society for

Engineering Education) will become indicators of "teaching contribution" for faculty, much as journal paper citations and external reviews are used to measure "research contributions."

Content quality assessment

Since the Content Commons is open to all, it will contain modules and courses in various stages of development and, hence, of various quality levels. How do we ensure that high-quality Connexions content is easily accessible to users? This requires both a means to evaluate and credential modules and a means to direct users to modules deemed of high quality.

Pre-publication review: Traditional publishers employ a peer review process. Each author submits a contribution to an editor who, based on reviews by the author's peers, decides whether to publish the work or not. Only then is the work publicly accessible. Pre-review is suitable in situations when the publication medium is scarce — the paper making up books, for example. Unfortunately, any pre-review procedure is too unwieldy to keep up with the fast pace of Connexions module and course development, where materials may change daily or even hourly. Moreover, the traditional binary decision to accept/reject a work is inappropriate when a module can improve in an evolutionary fashion. Accept/reject decisions also create an exclusive rather than inclusive community culture. In addition, pre-review does not support evaluation of modules and courses based on actual student learning in the field.

Post-publication review: Rather than make a single pre-review accept/reject decision regarding each module, Connexions opens up the editorial process to third-party reviewers and editorial bodies for post-review. While Connexions users will have access to all modules and courses in the Content Commons (whatever their quality), users will also have the ability to preferentially locate and view modules and courses rated high quality by choosing from a range of different *lenses* provided by third parties (see Figure 3). Each lens has a different focus. As a simple example of a lens, imagine a professional society independent of Connexions, such as the American Physical Society, that sets up a Web page containing a list of all physics Connexions modules and courses that it deems high quality. It can also post reviews of those modules and courses. The list would prove indispensable to students and instructors who trust the opinions of this society. Indeed, users will be able to configure their Roadmap browser to view preferentially those modules approved by the editorial bodies of their choice. Of course, users will always have the option of turning off all "lenses" to view the commons in its entirety.

Lenses will be distinguished by who rates a module or course and how it is rated. The following examples are characteristic but not exhaustive:

- *Editorial boards*: These can be set up by professional societies, student organizations, publishers, state or local educational boards, "consumer's unions," or ad hoc. Such an editorial rating is analogous to going to see a movie because a renowned critic rates it worthy. School boards can set up lenses to restrict student access to certain material. A university department can set up a lens that selects the modules and courses it has chosen to educate its students, much as a department chooses textbooks today. Index-based educational resources, such as Merlot (merlot.org) could also naturally serve as Connexions lenses.

- *Colleagues*: Instructors will wish to see the modules and courses that their peers at other institutions use. (Such a rating is analogous to going to see a movie because a friend recommends it.)

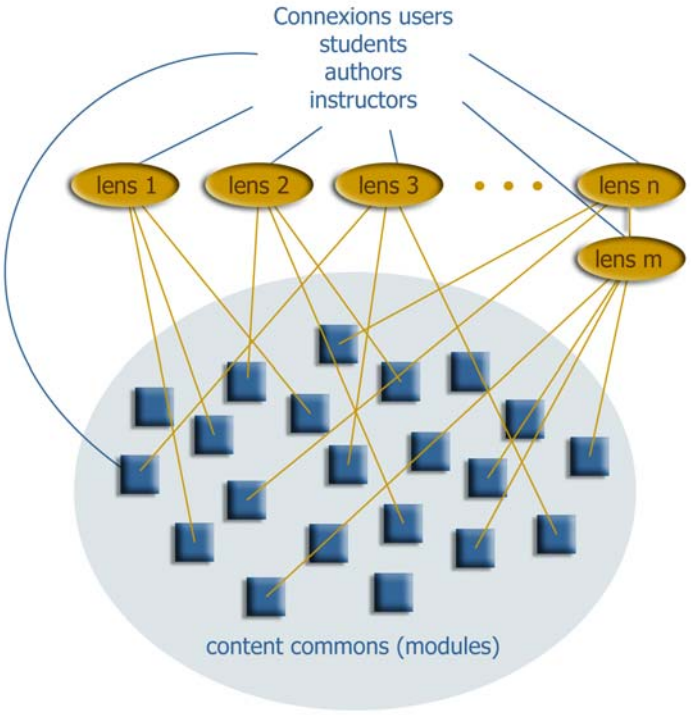

Figure 3: Connexions *lenses* for post-review.

- *Popularity*: A user may wish to see the "most read" or "most linked" module or course on a certain topic. (Such a rating is analogous to going to see a movie because it is a blockbuster.) Students may wish to see modules that "similar" students visited and found useful (collaborative filtering).

- *Learning assessment*: The learning outcomes of students using certain modules and courses could actually be tracked and this information provided to users. This would both help users select modules and courses and suggest improvements to the material.

Over time, multiple editorial boards with overlapping domains of interest will develop, creating a need to have a "lens for lenses" that reviews and rates the various editorial boards. We will refer to the community that sets up and runs the lenses as the *community of editor*s. Connexions is developing the software necessary to enable editorial lenses. However, for maximum scalability, Connexions will not be responsible for regulating the editorial boards or how they make their decisions. For related proposed editorial system proposals, see [9, 10].

Current content projects

So far in Phase 2 of our development, we have focused on three content communities that will serve as models for future Content Commons communities.

Holistic Rice ECE curriculum: Faculty at Rice University have embraced the Connexions approach to authoring, and their contributions have been limited only by our ability to feed their material into the system. Several modules now form the basis for one-third of the core electrical and computer engineering (ECE) courses at Rice. Over the next two years, we plan to develop a holistic Connexions undergraduate curriculum for Rice ECE, spanning 15 courses.

DSP beta project: Beginning at a Connexions workshop in August 2001, faculty members from the University of Illinois (D. Jones), University of Michigan (A. Hero), Ohio State University (L. Potter, P. Schniter), Georgia Institute of Technology (D. Williams), University of Wisconsin (R. Nowak), Polytechnic University (I. Selesnick), Cambridge University (N. Kingsbury), Norwegian University of Science and Technology (T. Ramstad, A. Gjendemsjo), and Rice University (R. Baraniuk, C. S. Burrus, D. Johnson) formed a cross-institutional "beta community" that plans to develop several hundred modules for teaching graduate-level digital signal processing (DSP) [11]. These initial modules will provide both a foundation of material and an organizational framework on which others can build – filling in gaps, drawing new connections, and adding problems, solutions, visualizations, and other teaching materials. Alfred Hero's new book with Cambridge University Press will form a backbone for the statistical signal processing materials.

DSP education is a ripe opportunity for Connexions to illustrate the community-building process [3]. With the rousing commercial success of DSP (the mathematics of cell phones, medical scanners, radar, and more), many graduate textbooks have migrated to the undergraduate level. The breadth of the field complicates graduate textbook development, as each school teaches widely ranging topics; one single text covering most topics would have to contain several thousand pages. Nevertheless, there exist many commonalities among the courses at various institutions. The Connexions DSP community plans to develop a common content base from which a customized DSP course can be woven for each school. DSP computer laboratories are also being developed [4], since the same theoretical background and many algorithmic details can be shared among laboratories based on different DSP chip architectures. Connexions' modularity and efficient authoring cycle are a natural fit for DSP lab courses, since the rapid evolution of DSP microchips means that lab texts fall out of date almost as soon they are printed [11, 12].

Music: Connexions allows musicians and authors to present and interconnect musical material in ways never before possible, mixing sound clips, videos, interactive exercises, and text. A wide range of courses is under development in music appreciation, music theory for children, the multicultural aspects of music, and music advice for parents.

Content in the areas of botany, biodiversity, bioinformatics, nanotechnology, applied mathematics, computer science, and civil engineering is also in active development [13, 14]. A new UNESCO initiative will see faculty from the developing world customizing Connexions content for use in their courses.

4. Project Team

Richard Baraniuk is a professor in Rice University's Department of Electrical and Computer Engineering (ECE) and a Fellow of the Institute of Electrical and Electronic Engineers (IEEE). For his research, he has received National Young Investigator Awards from the National Science Foundation and the Office of Naval Research, the Rosenbaum Fellowship from Cambridge University, the Young Alumni Achievement Award from the University of Illinois, and the Charles Duncan Junior Faculty Achievement Award from Rice. For his teaching, he has received the C. Holmes McDonald National Outstanding Teaching Award from Eta Kappa Nu (the electrical engineering honor society) and the George R. Brown Award for Superior Teaching from Rice. Dr. Baraniuk serves as the director of Connexions.

Don Johnson is chair and professor in Rice's ECE department. He is a Fellow of the IEEE and served as president of the IEEE Signal Processing Society in 1996–97. Currently he serves as a Signal Processing Society Distinguished Lecturer and directs the Society's Electronic Publication Experiment. He has been awarded five university-wide teaching awards at Rice and recently developed a new Connexions introductory course in electrical engineering focused on information. With Dan Dudgeon, he authored the textbook Array Signal Processing (Prentice-Hall, 1993).

Sidney Burrus is the Maxfield and Oshman professor of ECE and dean of the School of Engineering at Rice. He is a Fellow of the IEEE, a Humboldt Senior Awardee, a Fulbright Senior Fellow, and has received several IEEE research awards. He has received six university-wide teaching awards at Rice and has authored over 200 papers on research and teaching as well as five books, including: *DFT/FFT and Convolution Algorithms* (Wiley, 1985), *Design of Digital Filters* (Wiley, 1987), *Computer Based Exercises in Signal Processing* (Prentice-Hall, 1994, 98), *FFT Database* (PWS, 1995), and *Introduction to Wavelets and Wavelet Transforms* (Prentice-Hall, 1998).

Christopher Kelty is an assistant professor in Rice's Anthropology Department and an expert in the cultural and legal aspects of open source communities. His current research involves forms of property and contract in software/IT, the mechanization of thought processes, memory systems and universal languages, and information infrastructure and exchange in Europe, the US and South Asia.

Paul Dholakia is an assistant professor of management at Rice's Jesse H. Jones Graduate School of Management. His research interests lie in studying motivational psychology of consumers and studying online marketing issues such as virtual communities and online auctions. He also studies relational aspects of consumer behavior. He has published in a number of marketing, management and psychology journals and consults with firms in financial services, energy, health-care and other industries.

William Wilson is a professor in Rice's ECE department. He has been awarded seven university-wide teaching awards, been extensively involved in curriculum development at the department, school, and university levels, and recently developed a new Connexions course in semi-conductor technology.

Geneva Henry is the executive director for Connexions and for Rice University's Digital Library Initiative. Prior to joining Rice, she was a senior IT architect and program manager with IBM, where she was heavily involved in planning, managing, and architecting a number of digital library solutions for universities and museums worldwide *(one word)*, as well as for the US Department of Defense. Her career has included applied research in artificial intelligence (expert systems and natural language processing), text search, data modeling, and digital libraries at IBM, TRW and the RAND Corporation.

Brent Hendricks is the Connexions software system architect and technical lead. He received the BSEE degree from Michigan State University and the MSEE degree from Rice University. He has been a frequent contributor to open source software projects.

Janice Bordeaux has been involved for over twenty years in interdisciplinary research on cognition and learning in applied settings. Since 1995 she has developed specialized expertise in undergraduate educational reform and in assessing the impact of educational technology on teaching and learning at the university level.

Robert Maxfield was a co-founder in 1969 of ROLM Corporation, a computer and telecommunications manufacturer, where he served as executive vice president and director until ROLM was acquired by IBM in 1984. He is a consulting professor in the Management Science and Engineering department at Stanford University and a venture capital investor. He is president of the Maxfield Foundation, which he founded in 1986 to support scientific research and education. He serves as a director of Echelon Corporation, as a trustee of Rice University, and as a trustee of the Santa Fe Institute. He earned a BS in Electrical Engineering from Rice University in 1964 and a PhD in Electrical Engineering at Stanford University in 1969.

Current advisory board: Robert Maxfield (Rice trustee, advisory board chair), Burton McMurtry (Rice trustee), William Sick (Rice trustee), Cindy Lindsay (Rice trustee), James Crownover (Rice trustee), Mike Smith (Hewlett Foundation), and Cathy Casserly (Hewlett Foundation), Charles Henry (Rice vice provost and university librarian), James Boyle (Duke University School of Law).

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