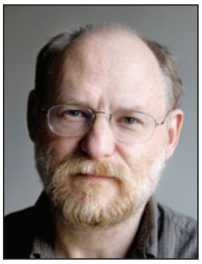
Crosslinks provides a way to organize access to OERs while helping students recognize links between the various subjects they study.

Crosslinks

Improving Course Connectivity Using Online Open Educational Resources

Haynes R. Miller, Karen E. Willcox, and Luwen Huang



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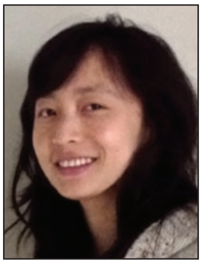

Luwen Huang

The flexibility of student pathways in today's university programs can make it difficult for students to perceive the relationships between the courses they take and to integrate their knowledge and skills in a useful way. In this paper we describe a tool we have developed to help students cope with this challenge.

Background

A student progressing through a university curriculum often experiences a lack of connectivity among courses. For example, third-year courses tend to assume facility with methods learned as a first-semester freshman, but as

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textbook ownership declines,[1] the problem of refreshing old knowledge gets more complicated. Conversely, first-year course lecturers often assume either that the material is intrinsically interesting (as it often is for them), or that the students know in advance how important it will be later in their studies.

The Massachusetts Institute of Technology (MIT) is just one example of an institution where these problems occur. Although MIT offers core courses in science, mathematics, engineering, and technology (STEM) constituting part of the school's General Institute Requirement and taken (or examined out of) in one form or another by all students, such disconnects are often observed, especially in the transition from core science classes to downstream engineering classes.

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Open educational resources (OERs), freely available on the Web, offer a remedy, and students also frequently make use of Google searches and Wikipedia entries. But the range of OERs available to a university student today is bewildering, perhaps nowhere more than in science and technology. A Google search on "eigenvalue learn," for example, produces more than 500,000 results, of widely varying quality and relevance and typically without any explicit connection with the actual course material a student has seen.

We have sought to address this dual problem of lack of connectivity and profusion of resources by creating the "Crosslinks" Web-based application, and in this paper we describe its rationale, features, and history. While the motivations to build this application were originally independent of OpenCourseWare (OCW), Crosslinks now demonstrates an interesting approach to curating OER resources with a specific audience in mind—students looking to refresh their knowledge of a STEM topic or understand how topics relate to one another.

[1] See Griffiths and Maron in this issue.

The Crosslinks website (crosslinks.mit.edu) is editable by anyone with MIT authentication credentials and open and freely accessible to all. We invite readers to explore it on their own.

What Is Crosslinks?

Crosslinks is a network that represents the relationships among topics and that connects topics to OERs. The nodes in the networks are *topics*, and the links represent *prerequisite or co-requisite relationships* between topics, grouped under five *facets of learning*, each describing the function of an educational resource:

- *Prepare*—prerequisite topics for review, enabling the student to identify "gaps" and critical points in her abilities
- *Relate*—closely related topics that tend to be learned together
- *Learn*—resources (e.g., course notes, modular videos, mathlets) where the topic might first be learned or that can serve to refresh knowledge or understanding
- *Advance*—topics that follow the current one, enabling the student to better grasp the context for the current topic
- *Apply*—links to interesting applications of the topic in later courses or in industry or other professions; answers the question, "How is this useful in the real world?"

Each topic has a Crosslinks webpage, which is structured in a uniform way. Figure 1 shows a snapshot of the Crosslinks page for the topic INTEGRATION BY PARTS. After a brief phrase describing the concept, along with links to external definitions (such as those in Wolfram MathWorld or Wikipedia), the page provides links related to the topic.

In populating the topics, we focused on basic concepts that tend to be taught in one subject, or by one department, and used in other follow-on subjects, frequently in other departments. As of the writing of this article, Crosslinks features 340 topics from 18 subjects across six departments at MIT.

Figure 2 shows a representation of a sample topic network. Each node represents a topic in the Crosslinks collection. The size of the node indicates the number of topics that link back to this node—the larger the node, the more foundational the topic.

The links between nodes indicate *Prepare-Learn* prerequisite relationships. In the example depicted, a mouse

FIGURE 1 Sample Crosslinks web page. Each such page includes a brief description of the topic and then links to open educational resources and to other topics, organized by the five sections of *Prepare*, *Learn*, *Relate*, *Advance*, and *Apply*.

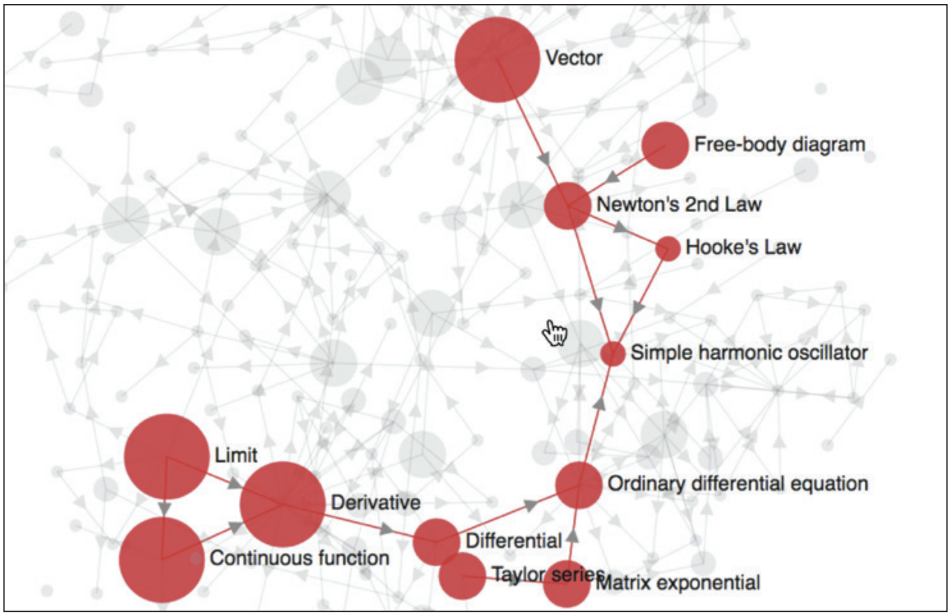

FIGURE 2 In the Crosslinks network, nodes are topics and links indicate prerequisite relationships between topics. The highlighted path shows the topics on which Simple Harmonic Oscillator depends.

over the topic Simple harmonic oscillator highlights the paths of prerequisite topics: Ordinary differential equation, Hooke's Law, and Newton's 2nd Law. These in turn depend on others, tracing back to the topics of Limit, Vector, Free-body diagram, and Taylor series.

This example illustrates an important aspect of the Crosslinks project: There are multiple possible representations and interpretations of learning pathways. The linkages represent the views of the student contributors, which are often (but not always) formed by the particular way a topic is presented in their classes.

At MIT, the simple harmonic oscillator is the foundation of the mathematics class 18.03: Ordinary Differential Equations. But vectors enter only tangentially (and normally); the matrix exponential is not directly connected to the mathematics of the harmonic oscillator, and while it is certainly an important part of the course it is not introduced by means of the Taylor series.

In contrast, a follow-on engineering class in dynamics or control might link these topics in different ways; for example, engineering classes often introduce the matrix exponential using the Taylor series. Students' view of linkages between topics thus involves some synthesis of their individual learning experiences.

In some cases, we found that faculty and students did not agree on the linkages represented in Crosslinks. Rather than worrying about publication on the site of learning pathways that are "wrong," we view this as an opportunity to explore student conceptions and misconceptions about the relationships among topics.

Divergences among student and faculty perceptions of linkages are also an excellent opportunity for faculty to discover connections across topics inferred by students, which, as disciplinary practitioners, we perhaps did not appreciate. This point does, however, indicate the need for some faculty curation and oversight to help vet the site's content. As with any wiki, the development of Crosslinks depends on contributions from all levels of expertise.

A related challenge occurred in the creation of the topic description. In our initial implementation, we created this piece of material (all other Crosslinks content is external links). This proved to be quite difficult and contentious—and indeed revealed a number of student misconceptions. In the current Crosslinks implementation, for this brief description we quote the lead sentence from the corresponding Wikipedia entry or some other authoritative source.

Crosslinks Conception and Design

The origins of Crosslinks can be traced to sustained efforts by the first two authors to better connect mathematics and engineering material taught across departments at MIT.

Miller had taught the basic ordinary differential equations class 18.03 for several years; it was taken by around 85 percent of MIT undergraduates and by virtually all engineering majors. He felt strongly that two-way communication with the engineering faculty was essential to make this class worth the enormous effort it took to run it. He asked engineers what parts of the subject were particularly important in their courses for which 18.03 was a prerequisite, and he sought good examples to enliven the mathematics. Conversely, it was important that these faculty know what was actually covered in 18.03 and how, so that they could meet their students where they were as they began their engineering studies.

Willcox, upon joining the MIT faculty as an assistant professor, was alarmed at an apparent lack of mathematical preparation of her aerospace engineering students and a lack of awareness among her faculty colleagues of what was taught, and how, in prerequisite mathematics subjects. She set about organizing a study of the flow of mathematical topics from math courses into and through the aerospace engineering major (Willcox and Bounova 2004).

The Crosslinks project emerged from a collaboration between the two of us. It was officially launched in 2010, thanks to support from an MIT Alumni Funds Grant. In addition to the two of us, the founding team comprised Heidi Burgiel, a professor of mathematics at Bridgewater State University on sabbatical leave at OCW, and Chad Lieberman, a former MIT undergraduate who at the time was working with Willcox as a graduate student.

Guiding Principles

The initial design of Crosslinks was informed by several principles:

- The primary target audience was MIT residential students.
- While initial motivation was drawn by connecting our own classes in ordinary differential equations and aerospace engineering, we envisioned the list of topics growing to cover other curriculum areas.
- We did not want to get into the business of producing new explanatory text; we wanted to use existing material.
- Similarly, we did not intend to create any new learning resources; we simply wanted to link to existing OERs.
- Links included in Crosslinks needed to be relatively stable, rather than transient links that would come and go with the semesters.
- The technical implementation needed a low barrier to editing, to facilitate sustained student contributions.

With these principles in mind, it was clear that MIT OCW offered a wealth of resources from classes and departments across the MIT curriculum. The links include both *Learn* resources that explain Crosslinks topics (often those of foundational mathematics and physics classes) and *Apply* resources that demonstrate downstream applications (often those in engineering classes).

Engaging Students

The initial phase of the project resulted in a Confluence Wiki, with a page structure very much as shown in figure 1, and came online in the fall of 2011. Advertised by posters around campus and in classrooms, it attracted substantial student use but almost no student contributions.

We hypothesize two reasons for the lack of student input. First, and most obviously, the Wiki authoring module was very hard to use. But we think a second factor was in play: Students are very conscious of issues of standing. Were they really in a position to identify some word as a bona fide “topic” and to identify authoritative links connected with this topic? Apparently the student consensus was “no.”

Crosslinks has benefited from a fantastic team of undergraduate research assistants who have created, populated, and linked most of the collection.

We hired undergraduate students as research assistants to help populate the site. Throughout its six-year history, Crosslinks has benefited from a fantastic team of undergraduate research assistants[2] who have created, populated, and linked most of the collection. Almost all of the entries have been done by hired staff; just a few entries but many more relationships among topics have been created spontaneously by students.

Reengineering to Enhance User Interface, Analytics

To address the concern about the Wiki authoring model, Crosslinks was reengineered to improve the user interface experience for students not only to access resources but also to contribute content. Huang joined the team in 2014 as technology lead for this effort, funded by a grant from the Lord Foundation. The site was restructured as a front-end (Web-based and mobile-responsive)

[2] Danielle Hicks, Adarsh Jeewajee, Carmela Lao, Czarina Lao, Katherine Nazemi, Emma Nelson, and Jenny Sui.

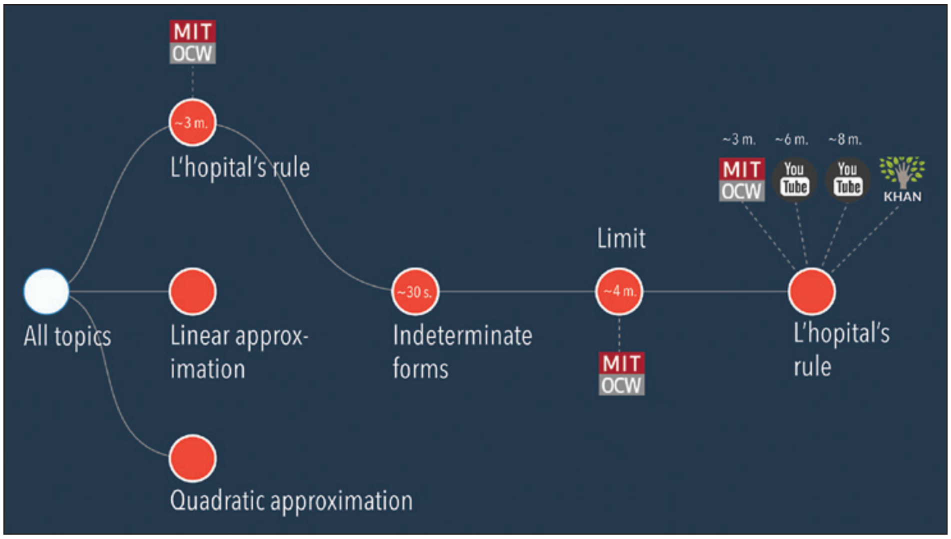

FIGURE 3 Illustrated path of a user's clickstream showing the topics visited, resources accessed, and time spent per interaction.

application that fetches content data from representational state transfer ("RESTful") Web application programming interfaces (APIs).[3]

Content data were restructured to be model-based, where topics and topic linkages are stored in a backend service created by the MIT Office of Digital Learning (ODL). This enables a much more scalable and simplified authoring experience: content is dynamically retrieved from the cloud and edits are saved back to the cloud. Users can easily select from topics, create linkages, and organize topics by subjects.

To discover user difficulties and reduce user interface friction, user experience research was conducted with students, faculty, and ODL content experts (MITx fellows). Iterative rounds of usability interviews, focus groups, and user testing led to the form and layout shown in figure 1.

In addition to marked improvement in student engagement and feedback, the technical restructuring enabled later implementation of clickstream analytics on individual topics and resulting insight on how students navigate and contribute to Crosslinks (further discussed below).

OCW and Beyond

As time went on, student Crosslinks editors pressed to include material other than OCW, especially in topics for which OCW material was lacking or deemed by the students to be less useful than other OERs. As a result, the Crosslinks collection now includes references to such resources. For example, Khan Academy videos provide a stable, high-quality set of links; and Wikipedia and Wolfram MathWorld, both heavily used by students, provide particularly useful links for brief topic definitions. Other outside references are included when suitable OCW resources don't exist, the resource is accurate and of high quality, and there is reason to believe that the link is fairly stable.

Throughout its six-year history, Crosslinks has benefited immensely from collaborations with the MIT ODL Strategic Engineering Initiatives team: Jeff Merriman, Cole Shaw, and Peter Wilkins; and from discussions with Dipa Shah at the MIT Teaching and Learning Lab.

In an exciting new development, in March 2016 MIT OCW embedded links to Crosslinks for every OCW course page whose resources are linked under Crosslinks *Learn* and *Apply*. Users can now browse an OCW course page, navigate to Crosslinks to see the topics covered in that course, see the associated resource links, and navigate to the OERs. This integration[4] demonstrates how Crosslinks can be used as a plug-in to an OER repository and enable navigation of the OERs. The Crosslinks codebase is open source and publicly available on Github,[5] and we invite others to fork the repository to build a Crosslinks customized to their own institution.

Crosslinks Use

Crosslinks implements custom clickstream analytics on top of the Crosslinks topic network as well as individual resource links in the *Learn* and *Apply* sections to track how users interact with topics and resources. Individual clicks on topics and resources are logged for every visitor session, so that granular interactions can be analyzed on the learner level.

[3] A brief explanation is provided at https://en.wikipedia.org/wiki/Representational_state_transfer.

[4] Carried out by OCW team members Joe Martis and Curtis Newton.

[5] https://github.com/wombats-writing-code/crosslinks-js

Figure 3 shows a somewhat simplified typical student pathway through Crosslinks. The student first visits the ALL TOPICS page, then simultaneously opens tabs on L'HÔPITAL'S RULE, LINEAR APPROXIMATION, and QUADRATIC APPROXIMATION. The student accesses the MIT OCW resource on L'HÔPITAL'S RULE and spends 3 minutes there before clicking to INDETERMINATE FORMS. There, the student spends 30 seconds before clicking to LIMIT, where the student accesses another MIT OCW resource and spends 4 minutes. The student finally clicks back to L'HÔPITAL'S RULE and accesses the MIT OCW resource, two YouTube videos, and a Khan Academy video (there were no more events registered after the Khan Academy visit and thus estimated time is unavailable for that resource).

These pathways recorded by the custom clickstream analytics enable fine-grained analysis of learner interaction with digital resources. For example, certain sequences of topics may be accessed more frequently than others. Or some resources may be more popular than others, but only when accessed in a particular sequence of topics.

These findings can help inform instructional designers and instructors who need to compose programs using OERs, and institutional administrators who need to survey and assess the landscape of their digital resources.

Conclusion

As open educational resources continue to proliferate online, structured ways to visualize and navigate them will become more important in order to facilitate and ensure their most effective use. Learners, instructional designers, and course authors need efficient access to resources.

Crosslinks provides a way to organize access to OERs, and is designed specifically to help students better appreciate the links between the various subjects they study at MIT. The design specifications allowed us to populate most of the site using student workers.

Our early vision was a resource "authored by MIT students for MIT students," like Wikipedia relying on peer curation to expand and maintain accuracy. Whether Crosslinks reaches that state is still open to question. But in the meantime it is providing a valuable resource for our students.

Reference

Willcox K, Bounova G. 2004. Mathematics in engineering: Identifying, enhancing and linking the implicit mathematics curriculum. Proceedings of ASEE Annual Conference, June 20–23, Salt Lake City.