

PROJECT SUMMARY

Overview:

The UTMOST Project seeks to understand two interrelated questions: How do students use textbooks? How can textbooks better support teaching and learning? The focus is on open source textbooks which can be made available in online versions that make full use of the capabilities of the Web. A particular challenge addressed is the need to promote student learning and use of mathematical and computational skills in STEM curricula.

Development and implementation activities are centered on PreTeXt, a new language for authoring scholarly documents. With a strict separation between content and presentation an author can execute a "write once, read anywhere" philosophy. This allows for multiple possible output formats, where the online HTML version is the most capable. It has powerful features for navigation, information hiding, and embedded interactive features, such as automated WeBWorK homework problems. Sage cells, powered by the global Sage Cell Server, allow for live embedded computational examples written using the open source computer algebra system, Sage.

The integrated educational research component studies how online open textbooks are used by instructors and students, by comparison with less dynamic PDF versions of the same textbook. Forty-nine courses, at a diverse group of institutions, will use PreTeXt books on calculus, linear algebra, and abstract algebra, as a source of data. The structure of a PreTeXt book allows data-collection of student use throughout the entire semester, organized by individual user, with resolution to the minute and at the level of individual components such as an example or a video. These fine-grained data provide new opportunities for the study of student textbook use, suggestions of ways to improve student engagement with the course material, and improvements in the design of the next generation of online textbooks.

Intellectual Merit:

The theoretically-driven research component of the UTMOST Project expands knowledge on design, through the study of textbook use by instructors and students in a large and diverse collection of classrooms. The project targets lower and upper division mathematics courses and serves as a model for courses in other STEM fields. The inclusion of two-year colleges and minority-serving institutions as test sites will study low-income and underrepresented minorities in STEM disciplines when they have access to these resources. The ability to capture fine-grained measurements of student activity provides exciting new possibilities for understanding student behavior, both in educational research and as guidance for instructors and authors. The information derived will inform the design of, the use of, and further research on, the impacts on student learning. The findings of this project will make a significant contribution to understanding resource use by students and instructors in real mathematics classrooms.

Broader Impacts:

Free textbooks, enhanced with open source software for live computations and homework, can make a critical difference in a student's success when cost is a barrier, and will increase opportunities for all students. In particular, this will contribute to the creation of a diverse workforce by lowering a key barrier for low-income students. These authoring tools can also create output formats (e.g., magnifications, Braille, math-to-speech) tailored for individuals with disabilities. Open textbooks and open software are publicly available and provide opportunities for independent study, increasing public scientific literacy and engagement with science and technology.

As an example, one of the 30 PreTeXt books available is Beezer's "A First Course in Linear Algebra." The online version of the book has 500,000 annual visitors. PreTeXt is already greatly increasing the supply of high-quality open textbooks, providing enormous benefits to students and society. All of this work is easily transferred to other STEM disciplines, so the national impact of PreTeXt textbooks is large, and the potential, across all disciplines, immense.

The UTMOST Project seeks to understand two interrelated questions: *How do students use textbooks?* and *How can we develop textbooks that better support teaching and learning?* Our focus is on open source textbooks that are available in free online versions and make full use of the capabilities of the Web. We address challenges in the undergraduate STEM curriculum, particularly the need to promote student learning and use of mathematical and computational skills.

Our work began with UTMOST-1, an NSF CCLI grant (2010–2014) that introduced the infrastructure now in use for the online textbooks in our current project. Items produced include preliminary versions of: (1) the Sage Cell Server, which enables live computations to be embedded in any web page (in particular, in any online textbook); (2) PreTeXt, a new authoring language which is specifically designed to produce interactive online textbooks; and (3) CoCalc, a cloud-based computing and collaboration platform which is now being developed as a commercial product. During UTMOST-1 we also founded the American Institute of Mathematics (AIM) Open Textbook Initiative and associated Editorial Board, which developed objective standards for evaluating open textbooks and continues to apply those standards to available textbooks.

Our current work is supported by UTMOST-2, an NSF IUSE grant (2016–2018). In this phase we began detailed studies on how students and instructors use online textbooks, focusing on linear algebra and abstract algebra. We compare the static (PDF) format with new dynamic versions incorporating the features developed in UTMOST-1. Our versions derive from PreTeXt and contain hundreds of embedded Sage Cells. To support our study, we developed new methods for tracking textbook usage. We have begun making these data available to instructors, so that student textbook usage can inform both the day-to-day and the long-term decisions made when preparing course material. We have also begun sharing this information with authors, with the goal of using real data to improve their books.

The analytics for student textbook use provide a good example of the cycle of innovation created by UTMOST, combining the efforts of experts in education research, software developers, experienced instructors, and authors. The analytics are enabled by a technical innovation—PreTeXt, which allows the structure of the text to be specified in detail. This includes the principal divisions such as chapters and sections, as well as smaller components such as definitions, theorems, examples, Sage cells, exercises, and solutions. The structural information is preserved in the interactive online version, making it possible to track the reader’s interaction with those elements. This is a new development and we are just beginning to understand how best to visualize and interpret this very fine-grained usage data, and how to combine it with the systematic observations obtained as part of our research study. A continuation of this cycle of innovation will involve using PreTeXt, in particular the detailed structure of the text, to help textbook authors enhance the learning potential of their books.

This proposal for UTMOST-3 will deepen and expand the results and techniques from our current education research study. Answers to our research questions will provide new understanding of how teachers and students use textbooks, and how we can further develop the next generation of online textbooks that better support teaching and learning. By helping authors to create high-quality open textbooks, across many disciplines, we anticipate a dramatic increase in the number of high-quality free textbooks, providing significant gains for society.

1 Overview

The UTMOST Project consists primarily of two major integrated components—**resource development** and **educational research**. These are complemented by **dissemination**, **professional development**, and **evaluation** activities. An overview of these components is provided next.

1.1 Resource Design and Development. As a Development and Implementation proposal, we will continue to improve and expand our tools that support the creation and effective use of open textbooks. Because we produce a variety of output formats (including print and PDF), optimized for a wide variety of devices (including phones), these texts are available to *all* students with minimal

requirements and no additional cost.

1.1.1 PreTeXt PreTeXt is a new markup language for scholarly documents. Its rigorous separation of content and presentation allow authors to execute a “write once, read anywhere” philosophy. Source documents can be converted to print, electronic PDF, online HTML, Jupyter notebooks, and EPUB for e-readers. Over 30 open textbooks authored with PreTeXt are now available freely online; they include rich features for navigation and embedded live computations, and some now have embedded WeBWorK exercises.

1.1.2 Legacy L^AT_EX We assist authors converting legacy L^AT_EX documents to PreTeXt, after which they can add new features enabled by PreTeXt. Boelkins’ *Active Calculus*, which we will use in our proposed study, is an example of a textbook originally authored in L^AT_EX, and thus previously only available as a non-dynamic PDF. The PreTeXt source produces a superior online version with embedded WeBWorK exercises. About half of the current PreTeXt books are a result of these conversions.

1.1.3 Sage Cell Server The Sage Cell Server allows *any web page* to include live and editable computations. This feature requires no setup, no login, and nothing more than a web browser with an Internet connection. In particular, authors can include interactive sessions with Sage in the online versions of their texts.

1.1.4 Analytics In UTMOST-2 we learned how to produce very fine-grained usage metrics about each reader’s interaction with the online textbook. Education researchers are only beginning to explore the potential of this rich form of data on student textbook usage. The dynamic online textbooks coming from PreTeXt also are new, and many of our research questions focus on how these new features impact instructor preparation and delivery of course material, and student interaction with that material. We expect our analytics to provide insight for those questions, and for the preliminary investigations to suggest ways to improve the analytics. We will validate our methods by comparing our new analytics to traditional data collected from surveys, logs, and classroom observations.

1.1.5 CoCalc CoCalc is an online hosting service, where students and faculty work collaboratively with a variety of open source software for STEM. Students can view material from PreTeXt books as Jupyter notebooks and also complete computational assignments as annotated Jupyter notebooks. Tools allow faculty to collect, mark, and return these exercises entirely in electronic forms.

1.2 Educational Research Study. As an Engaged Student Learning proposal, in this component we study how online open textbooks are used by instructors and students, and compare with less dynamic PDF versions of the same textbook. Building on tools, instruments, and procedures developed with our current IUSE award, UTMOST-2, we approach the work with an enactment perspective that attends not only to characteristics of instructors and resources that can influence instructors’ practice, but also to the ways in which using the resources can change instructors’ and resources’ characteristics.

We propose seven research questions focusing on the instructional aspect of resource use, with the goal of informing the work of both textbook developers and instructors. Our pilot testing in the spring 2017 semester, and our current study for the 2017–18 academic year, allowed us to develop instruments and test processes to collect data for investigating the access, openness, and transformative potential of dynamic online textbooks. We are in a position to begin data collection for the proposed study with full confidence in our tools, instruments, and procedures.

We are very excited by the potential of our development work for enabling the collection of very fine-grained data as students read their textbook online. This is a key tool developed in UTMOST-2 and we are just beginning to imagine, understand, and explore the possibilities. With our more traditional data collection through instructor and student surveys, logs, and classroom observations, we are able to match the two data sources. O’Halloran describes the potential for new research methods and refers to PreTeXt books as the “new generation of online digital mathematics textbooks.”

We will study 49 undergraduate mathematics courses using three textbooks authored in Pre-TeXt. The books we have selected are for first-year calculus, second-year linear algebra, and upper-division abstract algebra. Nine instructors will teach a course twice, participating in a workshop in the intervening summer. Those nine courses will also be studied comprehensively with more in-depth data collection. The remaining instructors will be chosen from a pool which represents a diverse range of institutional characteristics (including two-year colleges), student populations (including large minority populations), geographic locations, and faculty gender. For comparison, 9 of the 49 courses will be taught using non-dynamic PDF versions of the textbooks.

1.3 Workshops. Our workshops are a blend of software development, textbook development and editorial review, professional development, and dissemination. With support from the NSF and AIM, we have already organized seven such workshops on topics that are themes of this proposal. Participants for UTMOST-3 workshops will include test-site faculty, software developers, textbook authors, members of the AIM Editorial Board, educational researchers, and the evaluator. A novel feature of the workshops will be the presence of test-site faculty who have each used the same open textbook once during the prior spring semester, and will use it again the following fall semester. They will assist with modifying the textbook in ways that will make it more useful for their courses. The effect of these changes will be investigated in their second iteration of the course.

1.4 AIM Open Textbook Initiative. Since 2010, the AIM Editorial Board has become a valuable resource for the mathematics community through their careful process of evaluating open source textbooks. During UTMOST-2 the Board extended their scope to include editorial guidance for open textbooks. That work will continue in UTMOST-3. In addition, the Board seeks to work with groups from other areas to adapt the AIM **evaluation criteria** to other disciplines, which we see as an important first step in building a high-quality list of open textbooks.