Instructor and Student Uses of Technologically-Enhanced Undergraduate Mathematics Textbooks

Abstract

We present findings from a study of instructor and student uses of technologically-enhanced textbooks intended for mathematics majors in university linear and abstract algebra. The HTML format allows for pairing real-time viewing data with bi-weekly surveys from about 200 users of these textbooks. We describe processes of instrumentation and instrumentalization for faculty (in creating lecture notes) and for students (in reading the textbook). While both instructors and students tend to use the HTML textbooks as they would a bound textbook, the availability of real-time information about viewing allows for the identification of patterns of textbook use that are useful to inform instructors about student performance and textbook authors and designers about features that are most effective for users.

Purposes

Within the array of resources for teaching and learning, the textbook continues to be the most prevalent one for instructors and students. With new technological developments, textbook formats have been changing from paper to digital, open source formats, including sophisticated tools such as computing cells, annotation tools, and powerful search engines, easing access at relatively low cost. Importantly, open source textbooks never expire or go out-of-print and can be distributed at no cost to students, making them practically fully accessible. Particularly in countries in which post-secondary education costs are high wide accessibility contributes to eliminating financial barriers to education. However, the full potential of these textbooks can only be understood through empirical studies of how students and instructors actually use these

enhanced textbooks. The study we report here is part of the large federally funded project that seeks to describe how instructors and students use two open-source, technologically enhanced textbooks—hereafter HTML—one for linear algebra (LA) and the other for abstract algebra (AA), intended for math majors.

The majority of research on textbook use focuses on K-12 school mathematics (see Gueudet, Pepin, & Trouche, 2012) with some situated at the university level (Gueudet, 2017; Mesa & Griffiths, 2012). Research on uses of HTML university textbooks is in its infancy. Drawing on the extensive body of research at the K-12 school level we investigate the potential these textbooks offer to instructors and students by answering two questions: How do instructors use the HTML textbooks in creating their lecture notes? and How do students use their HTML textbooks as they study? In this paper, we focus on the linear algebra data due to space limitations.

Theoretical Framing

The study uses the documentational approach (Gueudet & Trouche, 2009). We document two processes: instrumentation and instrumentalization. In instrumentalization, the instructor decides how to use the resources in order to accomplish specific goals. In doing so, the instructor shapes the resources; but, simultaneously, the instructor learns from using the resources. This is the instrumentation process, which includes the affordances and constraints of the resources that can influence the instructor's work. The interaction between users and their resources can be studied via the development of documents for teaching and learning and the operational invariants that govern their use. A document is composed of the resources used for a specific activity plus the schemes of their utilization. Operational invariants are defined as users' considerations that guide the use of resources. In our study, we sought to describe instructors' documentation work for

planning and enacting lessons through instructors' lecture notes and students' instrumentation of their textbook for studying.

Methods

We use data collected in three semesters in 2017-2018 from 11 instructors and their students—six using the HTML-LA textbook, two using the HTML-AA textbook, one using the PDF-LA textbook, one using the PDF-AA textbook, and one using a different LA textbook. We recruited and university instructors from seven states. We collected one-time surveys about instructor and student attitudes about mathematics, textbook uses, and demographics; bi-weekly surveys (hereafter logs) to capture instructor and student uses of textbooks; and computer-generated data of textbook viewing at the classroom and individual-user level. We conducted weeklong visits with seven instructors that included observations of lesson planning, classroom video recordings, one-to-one instructor interviews, and student focus groups.

The interviews were analyzed using the documentational approach to identify operational invariants, noting how instructors said certain mathematical topics should be taught and their departures from the textbook. The video recordings were used to identify the evolving nature of the lecture notes. To investigate students' textbook uses we analyzed log questions that asked what textbook sections and textbook features they used in their most recent lesson and for what purposes, and questions that asked for student feedback on the computer-generated data of their individual-user level data, using a grounded theory approach and categories from Weinberg, Wiesner, Benesh, and Boester (2012).

Results

How do instructors use the HTML textbooks in creating their lecture notes?

We found a continuum of textbook use for planning and enacting teaching from extensive to minimal use of the technologically-enhanced textbook features. Some instructors created handwritten notes on paper (as full notes or as bullets points) referring to sections or pages in the HTML and PDF textbooks; some created videos that went over the textbook to emphasize particular definitions or theorems; others created Beamer or Power-Point presentations that included live links to sections in the HTML textbooks; others created sheets in Sage that linked the computational cells, the HTML textbooks, and free drawing capabilities using a tablet. For space reasons, we detail this last instructor's lecture notes that used the textbook's technologically-enhanced features extensively. During the weeklong visit, the instructor showcased a system of his resources for teaching, placing as a central resource the Sage worksheet (Figure 1). His students received the lecture notes before class and most viewed the notes using their personal computers during the lecture (Figure 2).

---Figures 1 and 2---

The Sage worksheet allowed the instructor to use cells for writing plain text and mathematical symbols (e.g., "Spanning Sets: Visualization") and Sage cells for computations and graphs. The instructor said that he copied and pasted the Sage code from the textbook's Sage cells and ran it in the lecture notes. In the classroom, he told his student to do the same (Figure 2). The parametrization gave students opportunities to run the code on their computers with various options and allowed them to rotate the graphs as they wished so they could look at them from different perspectives.

The instructor mentioned an operational invariant that shapes the design of his lecture notes and his use of the textbook for linear dependence:

> The geometric interpretation in $\mathbb{R}^3$ with more than two vectors linearly dependent better reveals the concept of linear dependence than the technical definition of linear combinations being zero.

This instructor said that while the LA textbook included technical definitions, it did not include geometric examples of concepts. This was a constraint because he had to search elsewhere for such examples, resulting in more time used for the design of the lesson. That constraint influenced the preparation of his lecture notes, thus revealing the process of instrumentation. Because of his view of the importance of geometrical visualizations for mathematical meaning making, he used an additional resource, a secondary textbook, where he located applications with visualization. The decision-making, informed by the operational invariant (i.e., the need for geometric interpretation), shaped his use of the HTML textbook for technical definitions and his use of the secondary textbook for geometric examples of concepts (instrumentalization). In Figure 1, the lecture notes were informed by an example of linear dependence regarding the geometric interpretation in $\mathbb{R}^3$ with more than two linearly dependent vectors. The students were then able to generate the vectors on their screens (Figure 2) and rotate the graph so it became clear that at least three of the vectors were on the same plane, thus being linearly dependent. In this way, geometry promoted students' meaning making of linear dependence and the set of resources used in this way facilitated this outcome. Other examples of instructor's instrumentalizating the HTML LA textbook included using navigation features (both in the textbook and in his lecture notes), theorems combined in lecture notes and hyperlinks that directly connected lecture notes and the textbook. All instructors created their lecture notes

maintaining the notation and definitions presented in the textbook, although they deviated from them at times as some other notation or definitions seemed more appropriate.

How do students use the HTML textbooks as they study?

The nature of the textbooks allows for capturing computer-generated data of textbook usage at classroom and individual-user levels. An example of computer-generated data illustrated at individual-user level is shown in Figure 3.

--Figure 3 here---

In Figure 3, the horizontal axis is time—midnight to 1am, Oct 30, with markers every 15 minutes. The vertical axis is textbook contents: a section, two subsections, and various elements (i.e., examples and solutions). Each green rectangle shows a student's use of textbook contents (vertical axis) in a period of time (horizontal axis). The student, whose use was captured in Figure 3, used more than 15 of the total 25 minutes to view examples and solutions: the student spent more than five minutes on example-COV, going back and forth between the example and theory in the subsection-LDS-COV. The student also spent up to two minutes on each of the solutions. Her log entry was: "I studied for my quiz by studying the examples in the book."

Students viewing data of their HTML textbooks occurred on all days of the week but more frequently when they had class and during class or those close to homework or examinations. Because not all students viewed the textbook on days close to the exam, we think that they may be using their class notes or other resources to prepare for those. The number of students per section who viewed the textbook varied, from as few as four to as many as 25 in any given day. In some sections, the textbook was heavily viewed by almost all students in the first day of class, suggesting that instructors may have spent time describing the features of the HTML textbook.

Three of the eight sections in the LA textbook (Systems of Linear equations, Vectors, and Vector Spaces) were the most viewed according to the heavy traffic across all courses throughout the semester.

In surveys and logs, students said that they used and liked a great deal practice problems, examples, and definitions, that they used theorems moderately, and that they rarely used proofs, propositions, properties, or corollaries. The students revealed various uses that varied depending on the element of the textbook; for example, they said that they used definitions to understand concepts, to figure out how to solve homework problems, to increase vocabulary, to check differences with respect to class work, to copy them into their notes, and to memorize them. A few said they did not use the definitions. Regarding practice problems, students said they used them to answer homework questions, to reverse-engineer methods of solving problems, to apply and work out textbook definitions, theorems, propositions, properties or corollaries, or to work out what was done in class. The viewing data confirmed some of these emphases: of 17,405 viewings in one semester for the HTML-LA textbook, 54% corresponded to solutions to problems, which took about 81% of the viewing time (~95K min); this was followed by about 31% of viewings of examples that took about 15% of the time. Theorems, definitions, Sage, and proofs took about 4% of the clicks each, but only about 5% of all the time of viewing combined. Students reported that they value the navigation features, the wide accessibility of the textbooks (they can be opened in any smart device), and that they are free. We did not find differences in student descriptions of textbook use between the HTML and the PDF or paper formats, although students using either format said that highlighting was a valuable feature that was not available in the HTML format.

Significance

The increasing availability of tools that facilitate the creation of textbooks that are open source and that can be free for students can alleviate the costs of attending a higher education institution. The possibility of mining the viewing data to understand how students take advantage of these textbooks can provide instructors with valuable information about sections that are difficult. This study was naturalistic in that the instructors were not trained to use the HTML features. As such, the findings provide baseline information that can be used to contrast with cases in which instructors work side-by-side with designers and authors to learn how to take advantage of the various HTML features.

Figures

Figure 1: In-class presentation of lecture notes embedded in Sage worksheet.

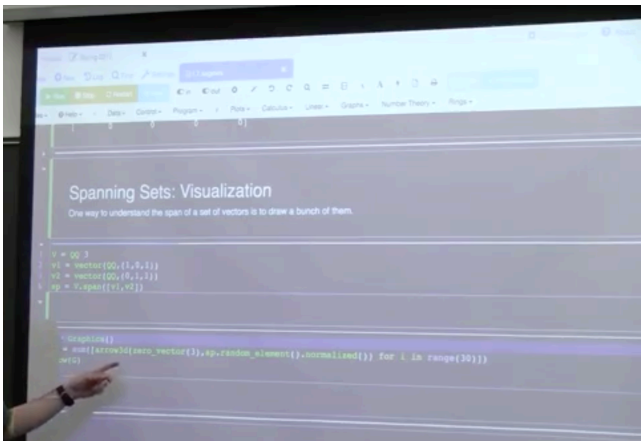


Figure 2: Simultaneous student work with lecture-note presentation.

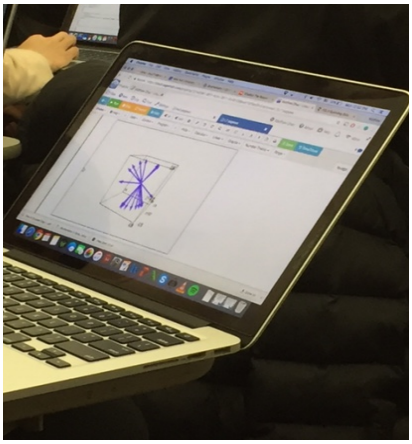
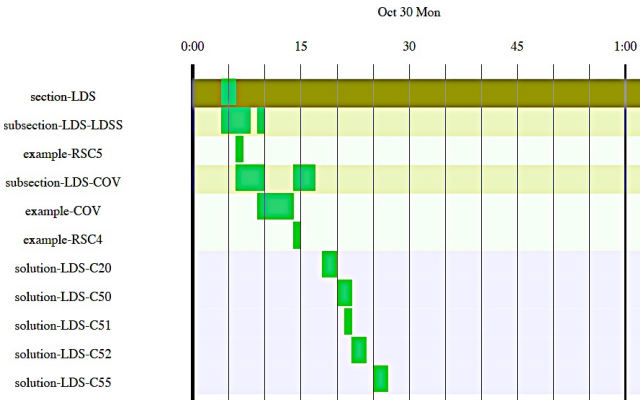


Figure 3: Visualization of student usage at the level of theorems, examples, solutions of the textbook with resolution to the minute.



References

(blinded reference removed)

Gueudet, G. (2017). University teachers' resources systems and documents. *International Journal of Research in Undergraduate Mathematics Education, 3*(1), 198-224. doi:10.1007/s40753-016-0034-1

Gueudet, G., Pepin, B., & Trouche, L. (Eds.). (2012). *From text to 'lived' resources: Mathematics curriculum materials and teacher development*. Dordrecth: Springer.

Gueudet, G., & Trouche, L. (2009). Towards new documentation systems for mathematics teachers? *Educational Studies in Mathematics, 71*, 199-218.

Mesa, V., & Griffiths, B. (2012). Textbook mediation of teaching: An example from tertiary mathematics instructors. *Educational Studies in Mathematics, 79*(1), 85-107.

Weinberg, A., Wiesner, E., Benesh, B., & Boester, T. (2012). Undergraduate students' self-reported use of mathematics textbooks. *Problems, Resources, and Issues in Mathematics Undergraduate Studies, 22*(2), 152-175. doi:10.1080/10511970.2010.509336