New College-Level Interactive STEM Learning Material: Findings and Directions

Frank Vahid and Alex Edgcomb
Dept. of Computer Science and Engineering, University of California, Riverside
Also with zybooks.com

Abstract

Student usage of textbooks is decreasing due to a disconnect from modern students, skyrocketing costs, and more. Furthermore, budget cuts have increased class sizes while decreasing teaching resources. These factors contribute to STEM attrition being 52% nationwide and as high as 80% in many colleges.

New learning material is needed that engages the modern student and is reasonably priced, yet self-sustainable and continually improving (in contrast to many free / open education resources). Auto-generated auto-graded homeworks are also needed, and in contrast to publishers' offerings, should be integrated with the learning material so students learn both theory and practice.

We are creating new college-level STEM learning material from scratch for the web, replacing textbooks as well as homeworks. The material uses less text and more interactive items, like animations and learning questions. Homework problems are integrated throughout, and are auto-generated and auto-graded with immediate feedback and allow repeated attempts. Instructors can configure the material to match the class syllabus. Students can be awarded points for completing the reading activities and the homework activities.

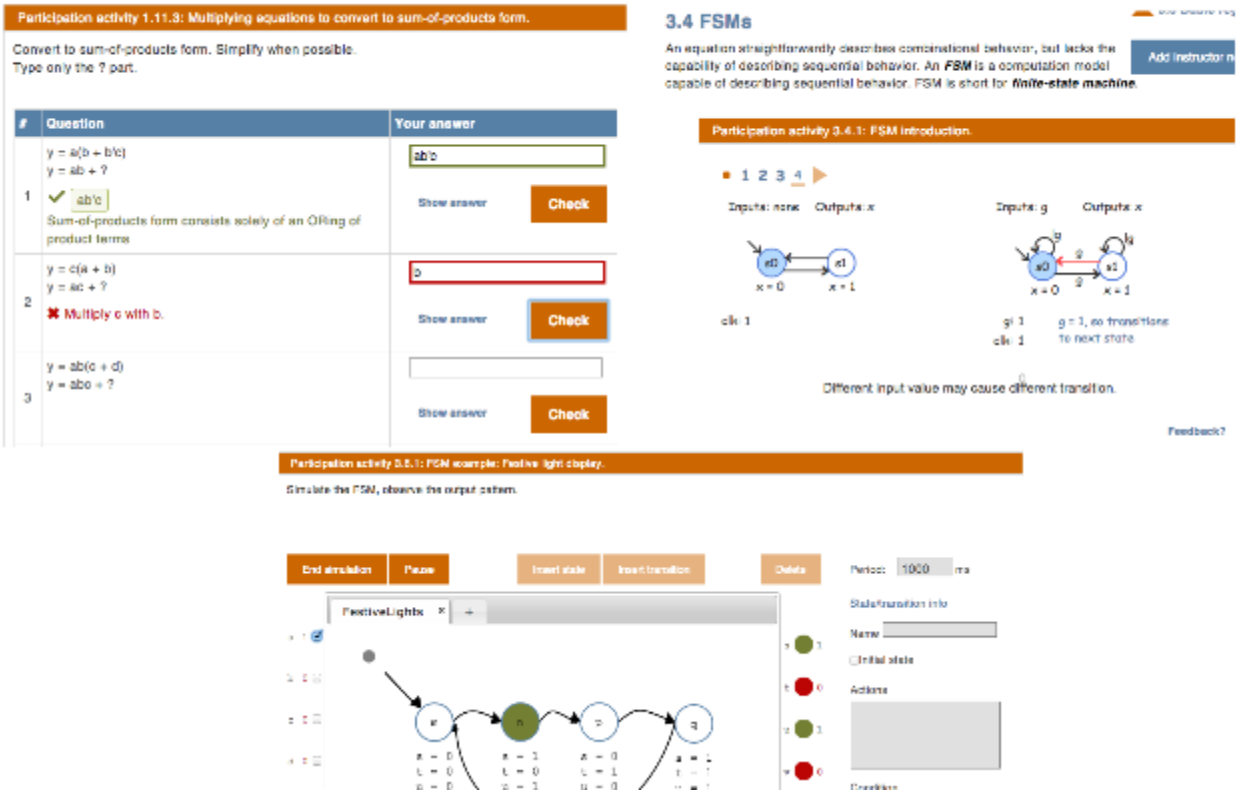
This paper summarizes several research findings conducted on the use of our material, including: Students learned more from the interactive material than from a popular textbook online, especially the initially weakest students who nearly reached the class average (144 students, controlled randomized study); courses whose only change was from a textbook to a zyBook saw improvements in projects, exams, and final grades (2000 students, across 3 universities); only 5-10 course points are needed to obtain nearly 100% completion by all enrolled students; 96% of students will earnestly attempt well-designed activities even if points can be obtained by clicking a "show answer" button; and reducing text while describing the same concept improves learning.

The materials have been used by 70,000 students at 300 universities thus far, and adoptions are growing. Feedback has been outstanding from both instructors and students, and studies show improved learning outcomes.

Introduction and background

Noting decreasing textbook usage by STEM college students, several professors began in 2012 to reinvent learning material to be interactive. The interactive material is created natively for the web, using less text and figures, and emphasizing use of interactive animations, learning questions, and integrated simulations and tools. The material also integrates auto-generated/auto-graded homework problems. The material is published as low-cost "zyBooks". Ten zyBooks exist, in computer science, engineering, and math, with more being developed. Adoptions have grown tremendously, with over 300 universities, and over 70,000 student users thus far. Research shows improved learning outcomes, and suggests best practices, as summarized in the rest of this paper.

Figure 1: Learning questions (top left), animation / less text (top right), simulator (bottom).



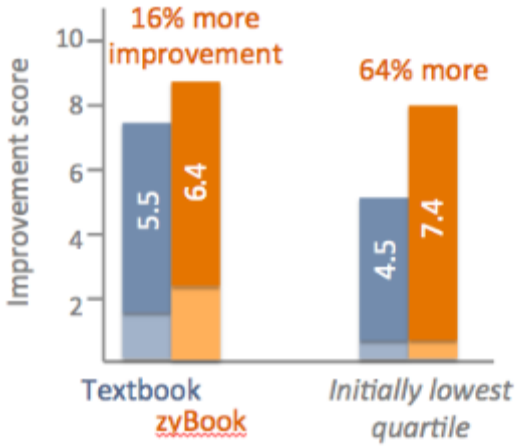
Student performance improvement using interactive material

We conducted two studies measuring student performance when using a static textbook vs. using web-native interactive material. The first was a randomized control study with

144 participants, each completing a pre-lesson quiz, a lesson (randomly-assigned either static or interactive), then post-lesson quiz [EdVa14].

Improvement is post-lesson quiz score minus pre-lesson score. Students assigned the interactive material improved 16% more (p-value = 0.016) than students assigned the static lesson. Further, the initially lowest-quartile improved 64% more (p-value < 0.001).

Figure 2: Textbook vs. interactive material (zyBook) controlled study: Substantial improvement, especially among the initially lowest quartile.



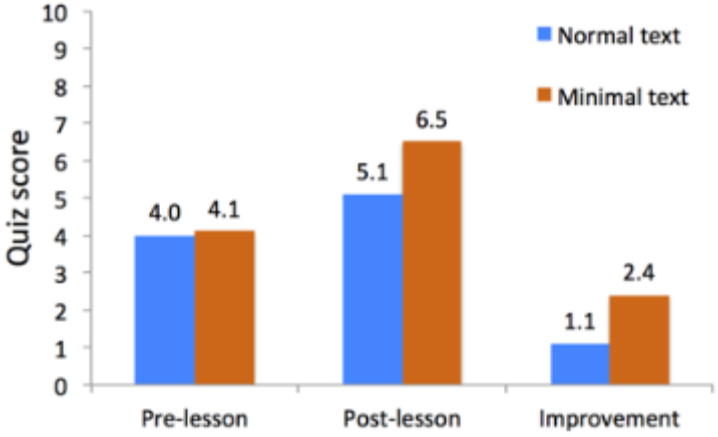
The second study was a cross-semester analysis with 4 classes at 3 universities with 1,945 students [Ed15b]. The first offering of each class used a static textbook; the second offering used interactive material. Each offering was taught by the same instructor with the same assessments, and during the same semester of the year, e.g., Fall semester.

Across all students, course grades improved by 0.28 points on a 0-4 point scale (p-value < 0.001), or 1/4 letter grade, from static to interactive textbook. More importantly, students in the lower quartile of the course improved by 0.38 points (p-value < 0.001), or 1/3 letter grade. Exam scores improved by 13.6% (p-value < 0.001) and project scores by 7.4% (p-value < 0.001) from static to interactive textbooks. 98% of the students subscribed to the interactive textbook and completed at least some activities on the interactive textbook. The average student completed 87% of the assigned activities in the interactive textbook.

Less text yields improved learning

In addition to replacing lengthy text passages by some text plus learning questions, animations, etc., we argue that any text should be as concise as possible, due to shorter text being more carefully read. We created and compared content styles using a lesson teaching

Figure 3: Normal vs minimal text controlled study: Students learn substantially more with less text.



Google search methods [Ed15a]. The two content styles were normal text (6-12 sentences followed by 1-3 examples) and minimal text (1-2 sentences followed by 1-3 examples). We conducted a randomized control study with 168 participants enrolled in Computing Technology course for non-computing majors at the Univ. of California. Each participant was randomly assigned one lesson style. We provided a pre-lesson and post-lesson quiz, each with ten questions.

The average improvement (post – pre) score for minimal text was 2.4 (6.5 – 4.1), higher (p-value < 0.01) than the average improvement for normal text of 1.1 (5.1 – 4.0). Thus, teaching the same topic with less text led to more learning. The conclusion is not that materials should be watered down, but rather that efforts should seek to minimize text (which is harder than writing lengthy text) while teaching the same core topics.

Students prefer interactive learning materials

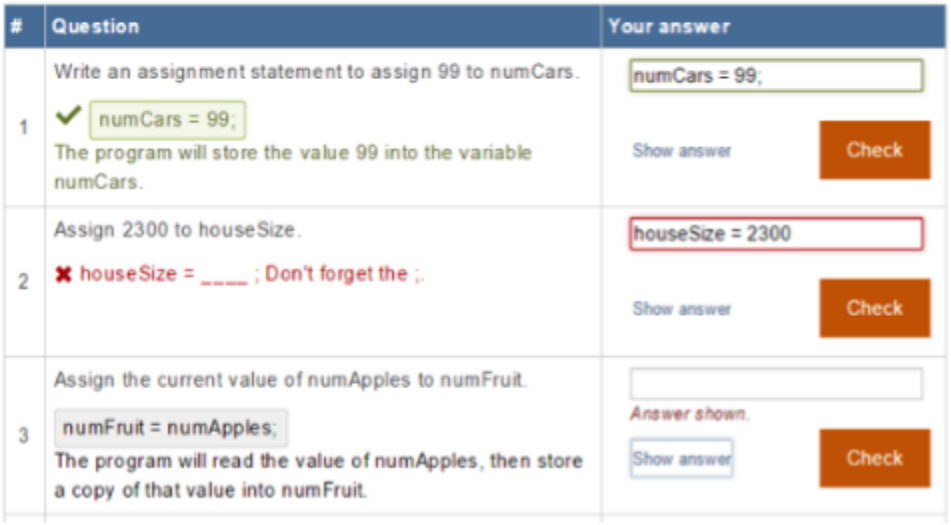
We surveyed student preference of static textbook vs. interactive material in a Computing Technology course at a Univ. of California campus. The course used a static textbook in Spring 2015 (563 participating students), and switched to interactive material for Fall 2015 (534 participating students).

A higher percentage of students acquired the interactive textbook (99.4%) than the static textbook (91.3%). A higher percentage agreed that "The textbook contributed to my success in the course" for the interactive textbook (97%) than the static (82%), and agreed that "When reading the textbook, I usually was able to understand the concepts being taught" for the interactive textbook (97%) than the static (87%).

Students earnestly complete activities even if answers are available

Our interactive content includes learning questions. Such questions are often assigned as homework. One type of question is a short answer, shown in Figure 4. Completion

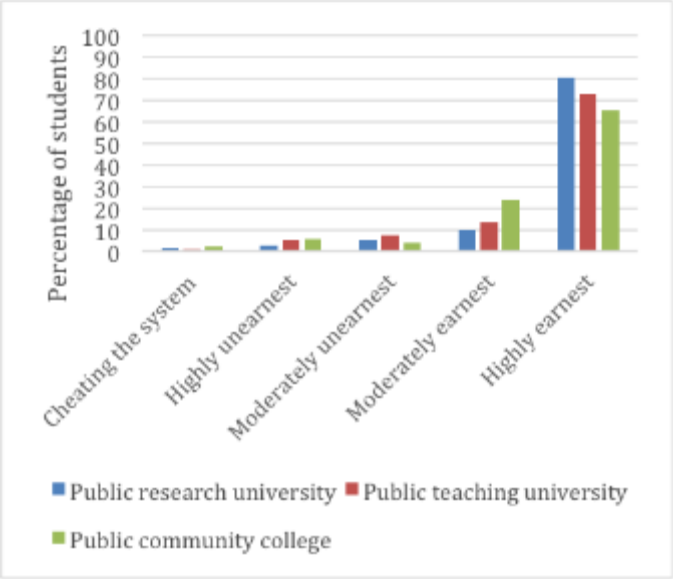
Figure 4: Short answer question set: (#1) Correct answer yields explanation, (#2) incorrect answer yields hint, and (#3) student can show answer.



is achieved when a correct answer is submitted. A unique feature is that "Show answer" shows the correct answer without awarding credit and without penalty. Instructors often ask whether most students will just show the answer and then copy/paste the correct answer, instead of earnestly attempting the question. An earnest answer is an answer in which the student first makes an attempt, before possibly showing the answer.

We gathered student usage data during Fall 2014 from 379 students at a public research university, 117 students at a public teaching university, and 57 students at a public community college. As shown in Figure 5, 85% of students earnestly attempted the short answer questions.

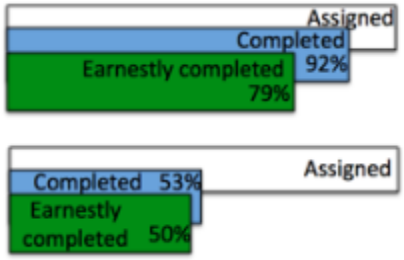
Figure 5: Students earnestly completed assigned reading, including across university types.



Only a few points need be awarded for interactive material

Instructors often ask how many course points are sufficient to ensure students complete interactive material activities. We analyzed behavior data of 1,394 students in 8 engineering classes at different colleges [EdVa15]. We found that surprisingly few course points—just 5 or 10 points (out of 100 points), and as few as 2 points—were sufficient to achieve over 90% average completion of activities by students. For comparison, assigning no points yielded only about 50% completion. Furthermore, we found that assigning points had only a minor impact on students earnestly attempting to answer questions, versus showing themselves the answer first, with earnestness changing only modestly from 92% to 86% when points were assigned.

Figure 6: Only 5 to 10 course points are needed for students to complete activities.



Points awarded	Earnestly completed
0	50%
2	77%
5	**83%**
10	**89%**
20	80%

Crowdsourcing: Students are good material raters, but not creators

The web enables new publishing paradigms, including having student users rate material as input to a continual improvement publishing process [Va15]. We investigated whether students could reliably rate the quality of learning material, by comparing student ratings to a professor's ratings [Ed15c]. The material included learning questions (multiple choice, short answer, and true/false) and animations. Some was created by fellow students with varying degrees of quality, and some was created by a professor.

25 students in an upper-division CS course rated the quality of 14 learning questions (7 from a professor, 7 from students). The top-20% of raters were strongly correlated with the professor's ratings (R-value = 0.82, p-value = 0.02). 177 students in a Computing Technology course rated 20 animations (1 professional, 19 from students). The top-10% of raters strongly correlated with a professor's ratings (R-value = 0.88, p-value < 0.001).

The study also found that most student-created content was low quality. One common problem was improper use of English.

Conclusions

Traditional college textbook efficacy continues to decrease, in part due to skyrocketing prices, mismatch with modern learning styles, and weak integration with online homework systems. Instead, web-native interactive learning material is on the rise, especially in college STEM. We have developed such material for 10 college subjects, replacing textbooks and homework systems, used at over 300 universities. We have shown improved learning outcomes, especially for initially-weaker students, via controlled studies as well as cross-semester analyses. We've shown that aggressively minimizing text also yields improved learning. We have shown that students like the interactive material, that students earnestly attempt such activities, and that only 5 to 10 course points need be awarded. We've also shown that students can reliably rate material, which may lead to new continual improvement paradigms. Future work includes experimenting with new paradigms for material creation and continual improvement, adding more applied examples to relate to modern students, and introducing more simulators/games to help build intuition and skill for deeper learning.

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Biographies

Frank Vahid is a professor of Computer Science and Engineering at the University of California, Riverside, and co-founder/chief technology officer of zyBooks. He is a pilot member of the University of California's Online Education project, co-developed an online college-level C++ programming course used nationwide, authored several textbooks and recently several online interactive zyBooks, and received several teaching awards and two ASEE best paper awards. He also conducts research in embedded systems hardware and software design.

Alex Edgcomb received his PhD in computer science at UC Riverside in 2014. He is a research specialist at UC Riverside, studying the efficacy of web-native learning material for STEM education. He is also a senior content and learning tool developer at zyBooks, a startup that develops interactive, web-native textbooks in STEM. He co-developed and is the teacher of an online college-level C++ programming course used nationwide.