Chapter 20
Open Content Authoring Tools

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Abstract. Education researchers often disagree about the best ways to improve student achievement. The difficulty of designing, conducting, and analyzing experiments means that there is often a dearth of empirical data to support or refute ideas. To design and conduct a simple randomized controlled experiment to compare two different ways of teaching requires a great deal of effort by a teacher or a researcher. The difficulty of conducting such experiments, and then later analyzing the results, may be why so few randomized controlled experiments are conducted in education. One of the goals of the ASSISTment System is to reduce some of those difficulties. We have built web-based tools that allow researchers to easily design, build and then compare different ways to teach children. These tools can administer randomized controlled experiments to large numbers of students. This paper describes these tools and describes a randomized controlled study that was conducted using them.

20.1 Introduction

Similar to many education researchers, mathematics education researchers tend to have heated arguments about what are the best ways to raise student achievement levels. Unfortunately, there is often a dearth of empirical data to support either side. This lack of empirical data is, at least partly, caused by the difficulty of designing, conducting, and analyzing experiments. While not all questions are best settled with randomized controlled experiments, some are. However, to design and conduct a simple randomized controlled experiment to try to compare two different ways of teaching requires a great deal of effort by a teacher or a researcher. Researchers not only must design and author the content for pretests, post-tests and each experimental condition, but they must also randomly assign students to conditions and collect and analyze large amounts of data.

The difficulty of conducting such experiments, and then later analyzing the results, are probably some of the reasons that so few randomized experiment are conducted in education. Intelligent tutoring systems can alleviate some of these

difficulties such as randomly assigning students, delivering content and collecting data. However, most tutoring systems require computer programming skills to accomplish these tasks and do not make it easy for researchers without programming skills to create new experiments.

One of the goals of the ASSISTment System is to reduce some of those difficulties. The ASSISTment System is a web-based tutoring system that includes web-based authoring tools that allow researchers to easily design, build and then compare different ways to teach mathematics. No computer programming skills are needed. These tools can administer randomized controlled experiments to large numbers of students.

This paper describes the ASSISTment System's tools for education research. We also describe how we designed and conducted a randomized controlled experiment to compare two ways of tutoring eighth grade math.

20.2 The ASSISTment System

The ASSISTment System is joint research conducted at Worcester Polytechnic Institute and Carnegie Mellon University and is funded by grants from the U.S. Department of Education, the National Science Foundation, and the Office of Naval Research. The ASSISTment System's goal is to provide cognitive-based assessment of students while providing tutoring content to students.

The ASSISTment System aims to assist students in learning the different skills needed for the Massachusetts Comprehensive Assessment System (MCAS) test or (other state tests) while at the same time assessing student knowledge to provide teachers with fine-grained assessment of their students; it assists while it assesses. The system assists students in learning different skills through the use of scaffolding questions, hints, and messages for incorrect answers (also known as buggy messages) (Razzaq et al. 2007). Assessment of student performance is provided to teachers through real-time reports based on statistical analysis. Using the web-based ASSISTment System is free and only requires registration on our website; no software need be installed. Our system is primarily used by middle- and high-school teachers throughout Massachusetts who are preparing students for the MCAS tests. Currently, we have over 3000 students and 50 teachers using our system as part of their regular math classes. We have had over 30 teachers use the system to create content.

We are attempting to support the full life cycle of content authoring with the tools available in the ASSISTment System. Teachers can create problems with tutoring, map each question to the skills required to solve them, bundle problems together in sequences that students work on, view reports on students' work and use tools to maintain and refine their content over time.

20.2.1 Structure of an ASSISTment

Koedinger et al. (Koedinger et al. 2004) introduced example-tracing tutors, which mimic cognitive tutors (Anderson et al. 1995) but are limited to the scope of a

single problem. The ASSISTment System uses a further simplified example-tracing tutor, called an ASSISTment, where only a linear progression through a problem is supported which makes content creation easier and more accessible to a general audience.

An ASSISTment consists of a single main problem, or what we call the original question. For any given problem, assistance to students is available either in the form of a hint sequence or scaffolding questions. Hints are messages that provide insights and suggestions for solving a specific problem, and each hint sequence ends with a *bottom-out* hint, which gives the student the answer. Scaffolding problems are designed to address specific skills needed to solve the original question. Students must answer each scaffolding question in order to proceed to the next scaffolding question. When students finish all of the scaffolding questions, they may be presented with the original question again to finish the problem. Each scaffolding question also has a hint sequence to help the students answer the question if they need extra help. Additionally, messages called *buggy* messages are provided to students if certain anticipated incorrect answers are selected or entered. For problems without scaffolding, a student will remain in a problem until the problem is answered correctly and can ask for hints, which are presented one at a time. If scaffolding is available, the student will be programmatically advanced to the first scaffolding problems in the event of an incorrect answer on the original question.

Hints, scaffolds, and buggy messages together help create ASSISTments that are structurally simple but can address complex student behavior. The structure and the supporting interface used to build ASSISTments are simple enough so that users with little or no computer science and cognitive psychology background can use it easily. Figure 20.1 shows an ASSISTment being built on the left and what the student sees is shown on the right. Content authors can easily enter question text, hints and buggy messages by clicking on the appropriate field and typing; formatting tools are also provided for easily bolding, italicizing, etc. Images and animations can also be uploaded in any of these fields.

The Builder also enables scaffolding within scaffold questions, although this feature has not often been used in our existing content. In the past, the Builder allowed different lines of scaffolds for different wrong answers but we found that this was seldom used and seemed to complicate the interface causing the tool to be harder to learn. We removed support for different lines of scaffolding for wrong answers but plan to make it available for an expert mode in the future. In creating an environment that is easy for content creators to use, we realize there is a trade-off between ease of use and having a more flexible and complicated ASSISTment structure. However, we think the functionality that we do provide is sufficient for the purposes of most content authors.

20.2.2 Skill Mapping

We assume that students may know certain skills and rather than slowing them down by going through all of the scaffolding first, ASSISTments allow students to try to answer questions without showing every step. This differs from Cognitive

Fig. 20.1 ASSISTment being built on the left and what the student sees is shown on the right

Tutors (Anderson et al. 1995) and Andes (VanLehn et al. 2005) which both ask the students to fill in many different steps in a typical problem. We prefer our scaffolding pattern as it means that students get through items that they know faster and spend more time on items they need help on. It is not unusual for a single Cognitive Tutor Algebra Word problem to take ten minutes to solve, while filling in a table of possibly dozens of sub-steps, including defining a variable, writing an equation, filling in known values, etc. We are sure, in circumstances where the student does not know these skills, that this is very useful. However, if the student already knows most of the steps this may not be pedagogically useful.

The ASSISTment Builder also supports the mapping of knowledge components, which are organized into sets known as transfer models. We use knowledge components to map certain skills to specific problems to indicate that a problem requires knowledge of that skill. Mapping between skills and problems allows our reporting system to track student knowledge over time using longitudinal data analysis techniques (Feng et al. 2006).

In April of 2005, our subject-matter expert helped us to make up knowledge components and tag all of the existing 8th grade MCAS items with these knowledge components in a seven-hour long "coding session". Content authors who are building 8th grade items can then tag their problems in the Builder with one of the knowledge components for 8th grade. Tagging an item with a knowledge component typically takes 2-3 minutes. The cost of building a transfer model can be high initially, but the cost of tagging items is low.

We currently have more than twenty transfer models available in the system with up to 300 knowledge components each. See (Razzaq et al. 2007) for more information about how we constructed our transfer models. Content authors can map skills to problems and scaffolding questions as they are building content. The Builder will automatically map problems to any skills that its scaffolding questions are marked with.

20.2.3 Problem Sequences

Problems can be arranged in problem sequences in the system. The sequence is composed of one or more sections, with each section containing problems or other sections. This recursive structure allows for a rich hierarchy of different types of sections and problems.

The section component, an abstraction for a particular ordering of problems, has been extended to implement our current section types and allows for new types to be added in the future. Currently, our section types include "Linear" (problems or sub-sections are presented in linear order), "Random" (problems or sub-sections are presented in a pseudo-random order), and "Choose Condition" (a single problem or sub-section is selected pseudo-randomly from a list, the others are ignored). The "Choose Condition" section is used to randomly assign students to a condition within an experiment.

The ASSISTment System has a Problem Sequence for every skill needed in sixth, eighth and tenth grade math according to the Massachusetts Frameworks. Teachers can easily choose a Problem Sequence from a list of approved sequences and assign them to their classes. Teachers can also create their own sequences from ASSISTments available in the system or from ASSISTments that they authored.

20.2.4 Running Randomized Controlled Studies

We are interested in using the ASSISTment system to find the best ways to tutor students and being able to easily build problem sequences helps us to run randomized
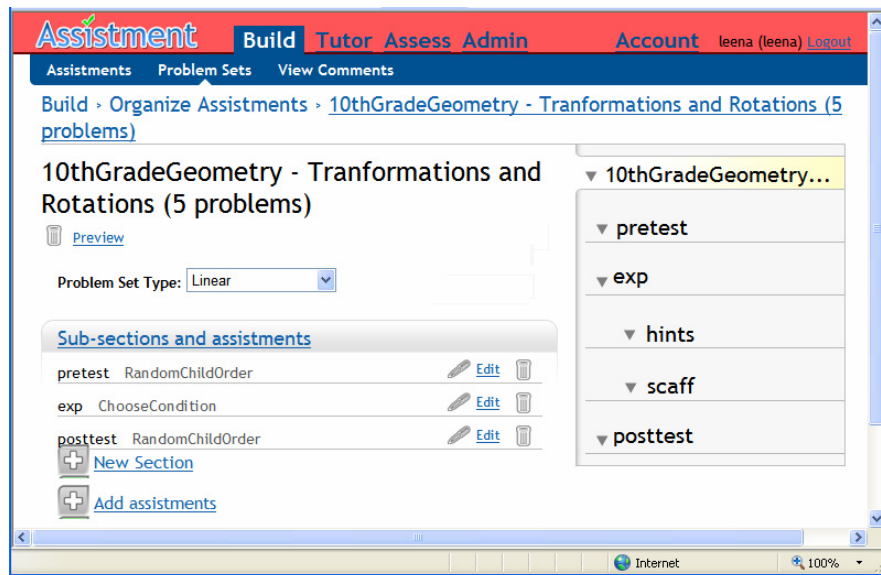
Fig. 20.2 A problem sequence arranged to conduct an experiment

controlled experiments very easily. Figure 20.2 shows a problem sequence that has been arranged to run an experiment that compares giving students scaffolding questions to allowing them to ask for hints. This is similar to an experiment described in (Razzaq and Heffernan 2006).

Three main sections are presented in linear order: a pre-test, experiment and post-test sections. The pre-test and post-test sections are Random sections and will present the questions in a random order. The system allows authors to label an ASSISTment as a "test" question, which means that students will get no feedback on that question. This allows us to compare gains from pre-test to post-test. The experiment section is a Choose Condition section. Within the experiment section there are two conditions and students will randomly be presented with one of them.

We have put together a way for researchers to sign-up for reports on their experiments using a Google Docs Spreadsheet. Researchers can fill out information about their experiment on the spreadsheet, such as the name of the experiment, the purpose, the ID number for the problem sequence and their email addresses. Researchers then will receive an email report every day that students participate in the study by working on the problem set.

The next section describes an experiment conducted with the ASSISTment System.

20.3 Example Randomized Controlled Experiment: Evaluating Educational Content on the Web

Relatively few intelligent tutoring systems (ITS) have become commercially successful even though they have been shown to be capable of producing significant

learning gains. This may be due to the high cost of building intelligent tutors and a large part of that cost comes from content creation. After surveying many authoring tools for tutoring content, Murray (1999) roughly estimated that 300 hours of development time was required for one hour of online instruction time. Anderson, Corbett, Koedinger, & Pelletier (1995) suggested that to build the Cognitive Tutor took a ratio of development time to instruction time of at least 200:1 hours. Although the ASSISTment Builder, an authoring tool for example-tracing tutors, produced a smaller ratio of development time to online instruction time of about 40:1 hours (Razzaq et al. 2009), a substantial amount of time is still spent creating content for the ASSISTment System as students (in middle school and high school) often use the system throughout the school year.

The World Wide Web has thousands of pages of educational content, some of them very well written. These web pages often include definitions, worked examples, images and animations. Can we use this wealth of instructional content on the web, saving time and resources spent on content creation? Can students learn from well-designed educational web pages?

The purpose of this study was to determine if students could learn from existing public web pages to help them solve problems in a tutoring system. What percentage of students would show any benefit from having visited a web page? Can we rank the effectiveness of educational web pages? How do these web pages compare to tutored problem solving that is specific to a problem? This section describes two studies that examine the use of educational web pages to help students solve math problems in an interactive learning environment. We found that students could learn from educational web pages and we did not find a significant difference between tutored problem solving and web pages.

20.3.1 Choosing Educational Web Pages

We decided to run this study with eighth graders and chose two topics that are typically covered in middle school to use in our experiment: Pythagorean Theorem and Venn Diagrams. We used Google.com's search engine to find web pages about the two topics on November 24, 2008 and December 15, 2008 and chose two "good" pages for each topic. Figure 20.3 shows the first page of Google's results for "Pythagorean Theorem."

We evaluated 13 pages about Pythagorean Theorem, using our own judgment before finding two that we wanted to use. For instance, we decided not to use the first result, found on Wikipedia.com (http://en.wikipedia.org/wiki/Pythagorean_theorem), because it appeared to be too advanced for eighth graders. We also excluded the state of New York's Regents Exam Prep web page (http://regentsprep.org/regents/Math/fpyth/Pythag.htm) because it had the answer to one of the questions in the problem set used in this study. We looked for colorful engaging web pages that contained background information about the skill as well as examples. We chose PBS's page on the Pythagorean Theorem, (www.pbs.org/wgbh/nova/proof/puzzle/theorem.html), because it was age appropriate and highly ranked by Google. Math Forum's page on the Pythagorean Theorem (mathforum.org/dr.math/faq/faq.pythagorean.html) was excluded because it contained a link to the PBS page.
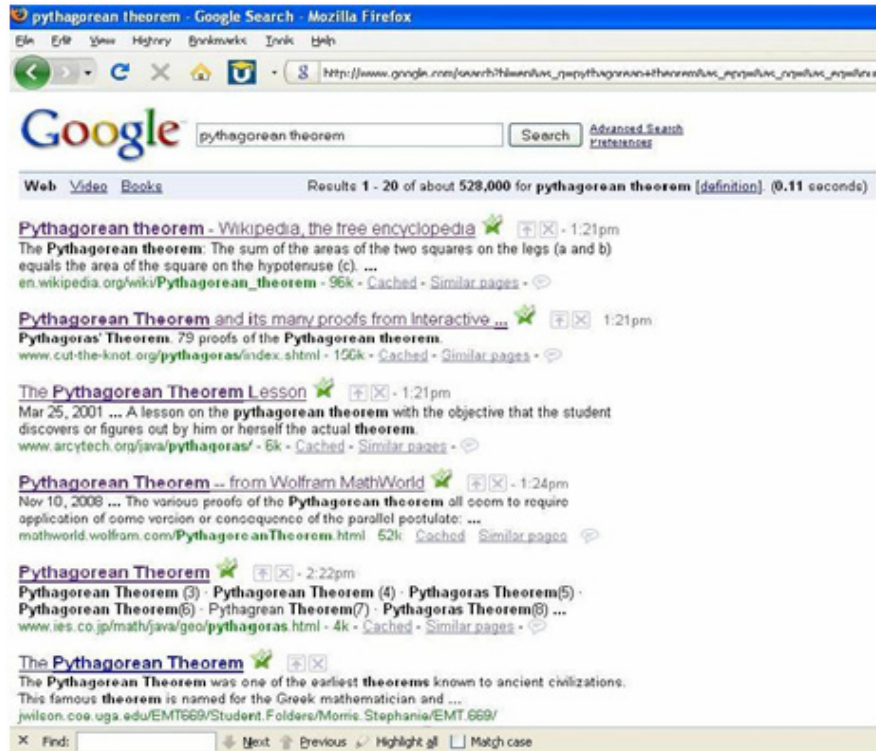
Fig. 20.3 The first page of Google's results for a search on Pythagorean Theorem accessed on November 24, 2008

Originally, we chose a "YouTube" video (http://www.youtube.com/watch?v=0HYHG3fuzvk) because it was the most viewed YouTube video on Pythagorean Theorem and clearly explained the concept. However, the middle school where our study took place blocked YouTube videos on student computers, so we did not use videos in this study. We replaced the video with a web page found at http://www.mathsisfun.com/pythagoras.html, which is shown in figure 20.4.

Similarly, we chose two web pages on the topic of Venn Diagrams. Found at http://regentsprep.org/Regents/math/venn/LVenn.htm and http://www.itl.nist.gov/div897/sqg/dads/HTML/venndiagram.html. In this way, we chose two web pages for each topic in the experiment.

20.3.2 How Does Viewing Educational Web Pages Compare to Tutored Problem Solving?

The purpose of this randomized controlled experiment was to compare tutored problem solving to viewing an educational web page. A previous study showed

Fig. 20.4 A web page about the Pythagorean Theorem at mathisfun.com

that students could learn from viewing a web page about the skill needed to solve a problem. The ASSISTment System normally uses tutored problem solving to help students solve problems, which requires students to work through problems step-by-step while the system provides hints and feedback on each step. Tutored problem solving has been shown to significantly increase learning especially for students with low math ability [5]. How does this compare to viewing a web page that is more general and does not specifically address how to solve the problem? Will there be a difference between the two conditions based on math ability? If viewing a web page could help students to learn as much or more than tutored problem solving, time and resources spent on content development could be significantly reduced.

20.3.2.1 Experiment Design

This study focused on two topics, Venn Diagrams and Pythagorean Theorem. This experiment used a repeated measures design: students participated in both conditions, web pages and tutored problem solving. The experiment controlled for the order of topics and the order of conditions, which were randomly assigned by
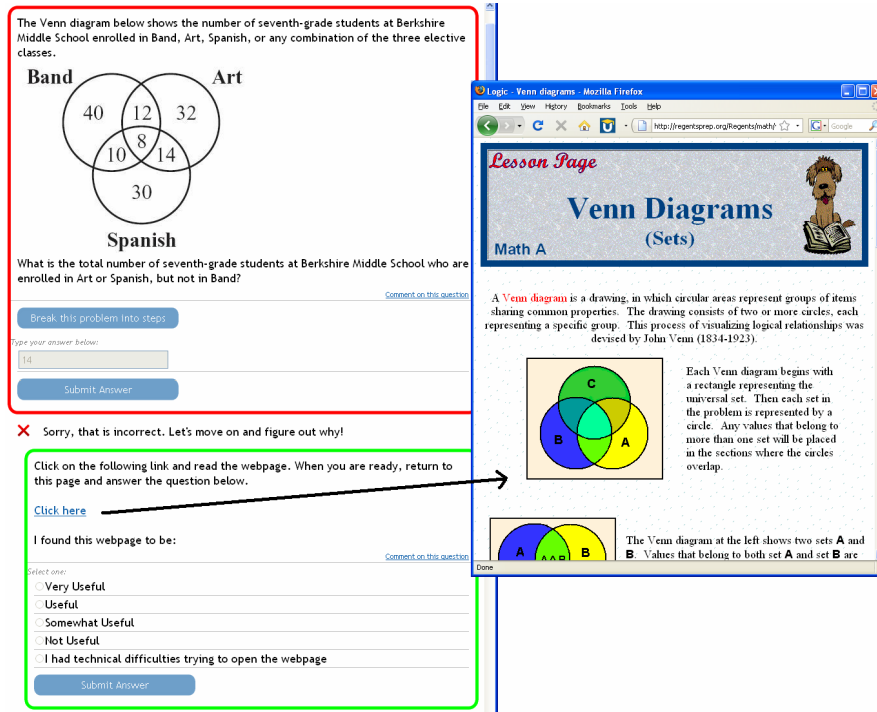
Fig. 20.5 Students were asked to click on a link to display a web page if they needed help

Table 20.1 Students were randomly assigned to one of four groups

	Group 1	Group 2	Group 3	Group 4
First	Venn Diagrams with TPS	Pythagorean Theorem with Web Page	Venn Diagrams with Web Page	Pythagorean Theorem with TPS
Second	Pythagorean Theorem with Web Page	Venn Diagrams with TPS	Pythagorean Theorem with TPS	Venn Diagrams with Web Page

student (see Table 20.1). A pretest and post-test was given before and after each topic, and learning was measured by gain score from pretest to post-test.

Figure 20.6 shows the section that was arranged for Group 3 shown in Table 20.1. This section presents Venn Diagram problems with web pages first and then presents the Pythagorean Theorem problems with tutored problem solving next. The experiment uses four similar sections and randomly assigns students to one of them by using a Choose Condition section.

**Fig. 20.6** One of the conditions in the experiment

This study took place during one period of a math enrichment class. Students had already been using the ASSISTment System during this class to help them prepare for the MCAS exam, therefore they were familiar with the system.

20.3.2.2 Results

Seventy-one middle school students (aged 13-14) participated in the study and 66 students completed both problems in both conditions. The Pythagorean Theorem topic was more difficult (mean pretest score = 45%) compared to the Venn Diagram topic (mean pretest score = 58%). The results showed that there was significant learning overall with a mean gain score of 33% [$t(68) = 7.48$, $p < 0.001$] for the Pythagorean Theorem topic and a 19% gain score [$t(67) = 4.18$, $p < 0.001$] for the Venn Diagram topic.

Table 20.2 Pythagorean Theorem, students learned slightly more with tutored problem solving than viewing the web pages

Math Ability	Condition	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
High	Web	0.348	0.076	0.195	0.500
	TPS	0.444	0.122	0.200	0.688
Low	Web	0.292	0.075	0.142	0.441
	TPS	0.500	0.138	0.223	0.777
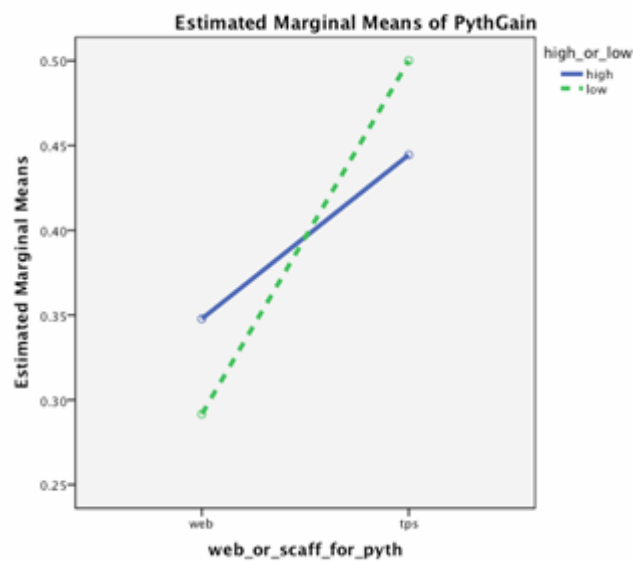
Fig. 20.7 Students learned slightly more from tutored problem solving in the Pythagorean Theorem topic.

The repeated measures analysis showed that the difference between tutored problem solving and web pages was not statistically reliable. Students had taken a practice MCAS test and a median split on the test scores was used to divide students into "low math ability" and "high math ability." No aptitude treatment interaction was found.

For the more difficult topic, Pythagorean Theorem, students learned slightly more with tutored problem solving than viewing the web pages [F(63, 1) = 7.45, p = 0.22]. (See Table 20.2 and Fig. 20.7)

20.3.3 Discussion

This section presented a study to examine the use of educational web pages to help middle school students solve math problems in a tutoring system. If we could

show that these web pages were effective, it could encourage tutoring system developers to make more use of the wealth of free educational content available on the web saving time and resources from content development.

The purpose of the study was to determine which method was more effective: tutored problem solving, which was specific to a problem or viewing a web page that was more general. This may be compared to studies such as Ringenberg and VanLehn's (2006) study of worked examples to hints that were specific to a problem. However, the web pages we used tended to have more background information and multiple examples as well as links to other web pages. No significant difference between the two was found in this study. Tutored problem solving appeared to help students slightly more when the topic was more difficult, though not reliably more. Could this result be because the tutored problem solving condition targeted specific problems and how to solve them while the web pages were more focused on the broader principles involved in the topic? We do not know, but believe that there is potential for future work here.

In conclusion, we believe the results of this study show that students can learn from educational web content and developers of ITS should be taking advantage of tutoring content on the web.

20.4 Conclusions

In this paper, we presented the ASSISTment System's tools for designing, conducting and analyzing randomized controlled experiments. No programming skills are needed to use these tools. We also described how we designed and ran an experiment using the ASSISTment System. We were able to easily design a repeated measures experiment that controlled for the order of conditions and the order of topics, which makes a stronger experiment.

We believe these tools will allow researchers to easily design and conduct simple randomized controlled experiments to compare different ways of teaching with interactive learning environments and perhaps settle more questions that educational researchers have.

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