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Deliberate Practice of Spreadsheet Skills when Using Copiable, Randomized, and Auto-graded Questions within an Interactive Textbook

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ABSTRACT

Spreadsheets are a core computational tool for practicing engineers and engineering students. While Microsoft Excel, Google Sheets, and other spreadsheet tools have some differences, numerous formulas, functions, and other tasks are common across versions and platforms. Building upon learning science frameworks showing that interactive activities are advantageous, an interactive textbook from zyBooks was created to provide students the opportunity to acquire spreadsheet skills by doing. Interactive components include stepping through animations, completing multiple choice and matching questions, and evaluating spreadsheet formulas and functions using 100+ auto-graded, randomized questions. While the interactive reading participation was discussed in previous work, the focus here is on auto-graded questions, sometimes called online homework. Fraction correct regardless of attempts, number of attempts before correct, and number of attempts after correct provided metrics to examine deliberate practice across three cohorts encompassing over 250 students. Sections grouped as General spreadsheet skills or Functions generally showed greater median correct, ranging from 76 to 90%, than sections categorized as Advanced spreadsheet skills, which led to median correct of 68 to 81%. Median correct also varied between different question types and decreased with question order, which aligns with questions being scaffolded. Finally, a hypothesis was tested: Adding a Copy sheet feature to the auto-graded questions would encourage deliberate practice and improve fraction correct between cohorts. Over 80% of students used the new Copy sheet button, and a statistically significant increase with large effect size in fraction correct between cohorts was found, which supports the hypothesis.

Key words: Learning technology; automated grading; knowledge transfer

INTRODUCTION

Completing calculations in spreadsheets is a common task for engineers and many other professions. Organizing data, calculating sums and averages, and visualizing trends in charts exemplify ways that spreadsheets empower engineering students and working engineers. Specifically related to chemical engineering education, the ubiquity of spreadsheets in the undergraduate curriculum was recently quantified and confirmed, especially when compared to earlier surveys (Hesketh, Grover, and Silverstein 2020).

While Microsoft Excel has been the standard spreadsheet application for decades (Clough 2016), the pervasive nature of spreadsheets has led to many alternatives, including Google Sheets, Apple Numbers, and Apache OpenOffice Calc. Paralleling the growth of free, cloud-based spreadsheets, spreadsheet education and training has dramatically expanded in recent years. While some books are still published for each new version of Excel or similar software, e.g., (Liengme and Hekman 2019), web-based videos provide abundant content on using spreadsheets. Initiating a web search quickly locates thousands of online resources, including step-by-step tutorials, video demonstrations, online courses, or in-person bootcamps or short courses. Specific to chemical engineering, AIChE's Academy offers webinars and courses from in-person, synchronous virtual, or fully online (AIChE 2020).

On one hand, despite the abundance of resources, students may feel limited with the master-student demonstration framework of spreadsheet training. On the other hand, instructors may not be able to measure or assess students' spreadsheet skills effectively and efficiently. Now, an interactive textbook platform provides a web-based platform for both content delivery, interactivity throughout, and auto-graded practice/homework questions. Therefore, connecting web-based visuals with best practices of active learning and sound learning theories present an opportunity to create a more student-centered, learning-by-doing tool for spreadsheets (Hawkins and Blakeslee 2005; Chi 2009; Chickering and Gamson 1987; Freeman et al. 2014; Felder and Brent 2016).

A major goal of engineering education is preparing students to transfer learning, and more specifically problem-solving skills, to a variety of settings (Bransford, Brown, and Cocking 2000). Interactive textbooks facilitate transfer by leveraging learning theories, including extensive visuals, breaking content into chunks, and significant interactivity. For example, animations transform static equations and figures into constructive, interactive exercises (Chi 2009). These visuals can stimulate short- and long-term memory formation (Medina 2008). Also, dividing content into smaller activities, such as matching exercises, is aligned with having a limited working memory and applies tenets of cognitive load theory (Chi 2009; Bowen, Reid, and Koretsky 2015; Sloan and Norrgran 2016; Paas, Renkl, and Sweller 2004). Overall, the interactivity through clicking, dragging, or typing engages the learner throughout an interactive textbook and applies the multiple representation principle (Mayer and Moreno 2002).

Auto-graded problems examine deliberate practice, or similarly, a mastery learning framework. By combining, defined, focused, and repetitive practice, feedback on correctness, explanation of errors, and availability of repeated formative assessment, successful learning outcomes have been measured in many previous studies involving music, medicine, sports, and higher education (Guskey 2007; West, Herman, and Zilles 2015; Ericsson, Krampe, and Tesch-Römer 1993; McGaghie et al. 2011; Plant et al. 2005). These tenets of deliberate practice will be leveraged throughout the results section. While some recent work divides purposeful practice from deliberate practice (Hambrick, Macnamara, and Oswald 2020), we will not comment on this divide. An advancement to more difficult levels is another element in deliberate practice, which is also called scaffolding. Scaffolding exercises from simpler to more complex have been shown to improve long-term memory through lessening load on working memory (Lape 2011) as well as allow self-regulation through multiple attempts (Steinberg 2014).

Interactive textbooks providing both content and assessment can lead to very high engagement, such as median reading rates up to 99% (Edgcomb and Vahid 2014; Edgcomb et al. 2015; Liberatore 2017; Liberatore, Chapman, and Roach 2020). Specifically related to spreadsheets, over 24,000 student interactions were collected for a cohort with a 1st quartile (75% of students) reading participation of 100% (Liberatore and Chapman 2019). In comparison, higher education reading compliance has been documented between 20 and 50% in most cases (Felder and Brent 2016; Burchfield and Sappington 2000; University of Indiana College of Education 2018). Beyond interactive spreadsheet content, auto-grading of spreadsheets has recently been discussed (Hekman 2019), multiple attempts were allowed to have students' spreadsheets align cell locations with an instructor's template. Auto-grading provides immediate feedback when learning spreadsheet skills, which could lead to significant time savings for faculty and teaching assistants.

Since our past contributions have focused on engagement and reading of interactive textbooks, this manuscript will focus primarily on auto-graded questions. Thus, auto-graded questions allow for research related to scaffolding and deliberate practice to be studied using a new technology. Specifically, a new feature allowing students to quickly copy the question spreadsheet from the interactive book into the application of their choice provides a case study. The hypothesis is that a new copy sheet feature allows learners to focus on the task at hand and more efficiently complete repetitive attempts, especially those with greater than 10 cell entries, and thus, will lead to a greater fraction correct solving spreadsheet questions over a previous cohort.

Table 1. Sections divided into three categories from* Spreadsheets Essentials *zyBook for 2020 cohort. The number of questions for each category and section are noted in parentheses.

General skills (37)	Functions (38)	Advanced skills (48)
Spreadsheet basics (5)	Spreadsheet functions (7)	Error and basic statistics (9)
Formulas (12)	Math and trigonometry functions (9)	Interpolation (10)
Sort and filter (5)	Logic and count functions (8)	Integration and numerical integration (19)
Charts (7)	Matrix functions (14)	Systems of linear equations (10)
Trendlines (3)		
Solvers (5)		

MATERIALS: AUTO-GRADED, RANDOMLY GENERATED SPREADSHEET QUESTIONS

The spreadsheet content resides within an interactive book from zyBooks – a Wiley brand. Interactions are completed within any HTML5-compliant browser without additional plug-ins. Specifically, spreadsheets are covered as one chapter within the *Material and Energy Balances* zyBook or a standalone title – *Spreadsheet Essentials* (Liberatore 2020). Spreadsheet content is split into configurable sections; Dividing the sections into three categories will facilitate discussion later (Table 1).

A brief description of the format of sections or subsections is provided here with details provided in earlier publications (Liberatore and Roach 2018; Liberatore and Chapman 2019). First, content is divided into manageable chunks, which is in concert with cognitive load theory (Chi 2009; Bowen, Reid, and Koretsky 2015; Sloan and Norrgran 2016; Paas, Renkl, and Sweller 2004). Content advances through Define, Demonstrate, Practice, and Challenge. Define provides definitions of new terms, and these terms are searchable similar to other electronic books. Demonstrate translates figures and derivations into animations. Over 45 different spreadsheet animations create new content in 3 to 6 steps where students need to click and participate with each step. Animations generally take less than 2 minutes to view, which aligns with human's attention span, e.g., (Wistia 2016). Learning questions provide Practice without penalty using a combination of multiple choice, true/false, and matching. Learning questions apply sound learning theories related to immediate feedback and backward fading (Lang 2016). Overall, more than 290 clicks are required to complete reading participation of the 14 interactive spreadsheet sections.

Finally, over 120 auto-graded questions – called challenge activities – will be examined in detail. The Challenge component automatically grades students' work and randomizes numbers, cell

Figure 1. Auto-graded spreadsheet question related to linear interpolation. Fifth of five question levels. Copy sheet button is located on the lower left of the spreadsheet. Randomized content includes both numbers and cell locations.

locations, and content for each student and attempt. Scaffolding is used for both learning questions and challenge activities, so easier questions precede harder questions (Felder and Brent 2016).

An example question level visualizes random numbers for pressure, temperature, and volume for completing linear interpolation (Figure 1 and Movie in Supporting Information). Also, a new feature being studied here is the Copy sheet button located below the spreadsheet on the left-hand side (Figure 1). With up to 50 cells containing content as part of the question in many cases, a common complaint from students was the difficulty translating the question into their spreadsheet application. Previously, cell contents could not be highlighted or copied in the interactive textbook, so only manual translation of the cell contents in a question could be performed to transfer the cell contents into a spreadsheet application. Now, after clicking the Copy sheet button, a student can paste their question's cells into a spreadsheet application using a paste button or key command. While copy/paste has been available in spreadsheets for decades, combining personalized content and assessment in the zyBook is unique. With each student and attempt, the numbers and cell locations can change. Many single questions have thousands of versions. Thus, being able to quickly translate a set of numbers, perform calculations in a spreadsheet, and return to the interactive textbook to check correctness is innovative. Also, combining the words of the problem statement with visuals of either a spreadsheet or figure aligns well with the multiple representation principle introduced earlier (Mayer and Moreno 2002).

Student interactions from three cohorts at a public research institution during the Spring 2018, 2019, and 2020 semesters will be discussed. Each cohort consisted of 103–104 students with 60–65% male and 35–40% female, and most students were freshman majoring in chemical engineering and environmental engineering. The authors acknowledge that a limitation of the study is examining the data as a function of gender or other diversity criteria as well as the lack of external metrics, such as GPA, to normalize the findings. The *Material and Energy Balances* zyBook (Liberatore 2020) was required, and the spreadsheet content was 1 of the 9 chapters assigned as part of a material and energy balances course. Students were awarded 10% of their final grade for completing both reading clicks and auto-graded challenge activities for the semester. Specifically, over 500 total questions were available in 2020 book, and the spreadsheet questions accounted for 123 questions. Students' grades allowed for a forgiveness of 15 incomplete/incorrect questions (Martin, Newstetter, and Le Doux 2019). However, the metrics presented here are uncorrected, i.e., do not account for the forgiven questions. Many students received spreadsheet instruction during high school and/or a previous semester, which was not accounted for in this study. Students gave positive to very positive feedback related to the interactive format when surveyed (Liberatore 2017; Liberatore, Chapman, and Roach 2020), which will not be expanded upon here. Students withdrawing from the course were included. Thus, averages are normally lower than medians, since students who withdrew from the course commonly did not attempt many of the challenge activities. In addition, the 2020 cohort experienced campus closure about halfway through the semester due to COVID-19. The shift to remote course delivery did not show significant differences in reading participation or similar common forms of engagement within the zyBook. However, ten students withdrew from the course in 2020, compared to five students per cohort in 2018 and 2019.

Box plots represent the middle 50% of data, including 1st quartile, median, and 3rd quartile. Thus, box plots minimize the effects of small numbers of outliers that can skew averages; for example, a student not attempting any questions in a section earned 0% correct. Average or mean values may also be included in box plots to visualize skewness. Hypothesis testing was conducted between pairs of data. Executing t-tests outputs p values with statistical significance being considered when $p < 0.05$. When $n > 20$, t-tests are justifiable even with nonnormal distributions, and different types of nonnormal distributions showed coverage probabilities of 91% or higher (Bonett 2006a, 2006b). Additionally, one-way analysis of variants (ANOVA) was performed when more than two data sets were compared.

RESULTS AND DISCUSSION

Leveraging the elements of deliberate practice introduced above, a quantitative research study begins with a brief discussion of reading participation. Next, the analysis of metrics across different spreadsheet concepts, question order, and question type examines deliberate practice across multiple cohorts. A final results section addresses the hypothesis that the ability to quickly copy the contents of a spreadsheet into an application of choice will improve fraction correct on auto-graded questions, specifically questions that required the transfer of large numbers of cells.

Cohorts and Content

Since both content and auto-graded problems are included in a single tool, a brief summary of reading participation to three cohorts expands upon previous work (Liberatore and Chapman 2019). High reading participation was recorded across all cohorts. Median reading rates were 100% for all three cohorts, and 1st quartile reading rates were between 98 and 100% across the three cohorts (see Supporting Information). Therefore, higher student engagement through reading participation related to spreadsheets was measured compared to the material and energy balances content (Liberatore, Chapman, and Roach 2020). Thus, interactivity via reading participation seeded further study of interactive challenge activities.

The fraction correct by student on spreadsheet challenge activities across three cohorts (Figure 2) showed statistical similarity ($F(2, 287) = 0.19$, $p = 0.82$). Thus, most subsequent figures and tables aggregate the three cohorts. Median correct was very high at 94 to 99% across the cohorts. Mean

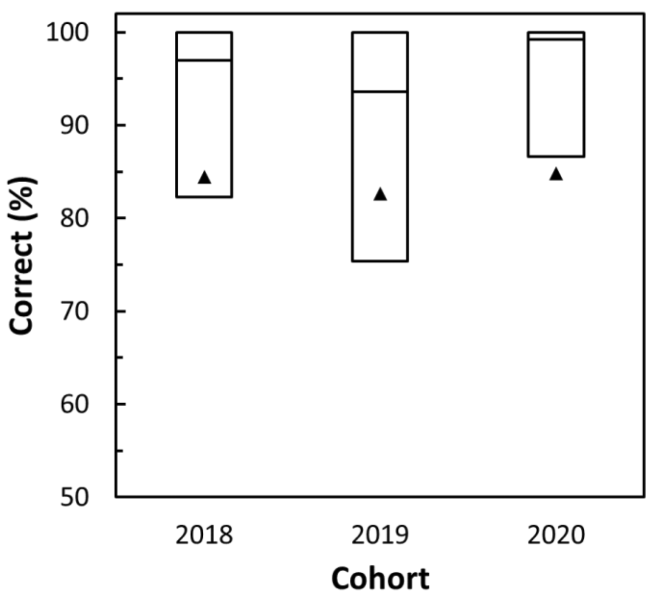

Figure 2. Correct (%) for students on 100+ challenge activities related to spreadsheets across three cohorts. Triangles represent mean.

correct varied between 83 and 85%, which is biased by a small number of students not attempting many or all of the questions. The 2020 cohort had the highest median and 1st quartile correct, which may be related to the new Copy sheet feature that will be discussed later. The 1st quartile correct varied from 76 to 87%. Thus, three quarters of the students exhibited proficiency completing spreadsheet tasks across all sections, which will be elaborated on next.

Central elements of deliberate practice, namely feedback on correctness, explanation of errors, and availability of repeated attempts, are measured with fraction correct and attempts before correct data across different spreadsheet content. Fraction correct on challenge activities differed by section categories of General spreadsheet skills, Functions, and Advanced spreadsheet skills (Figure 3). The number of questions in each category varied between 37 to 48 (Table 1). Median correct varied with 87% for General spreadsheet skills, 83% for Functions, and 72% for Advanced spreadsheet skills. Performing ANOVA and pairwise hypothesis tests found statistically significant differences between each category (see Supporting Information). This trend may be expected as some to all of the general and function concepts and skills were introduced in high school or earlier college courses (based on conversations with students in recent years), while advanced skills require additional math and problem-solving skills.

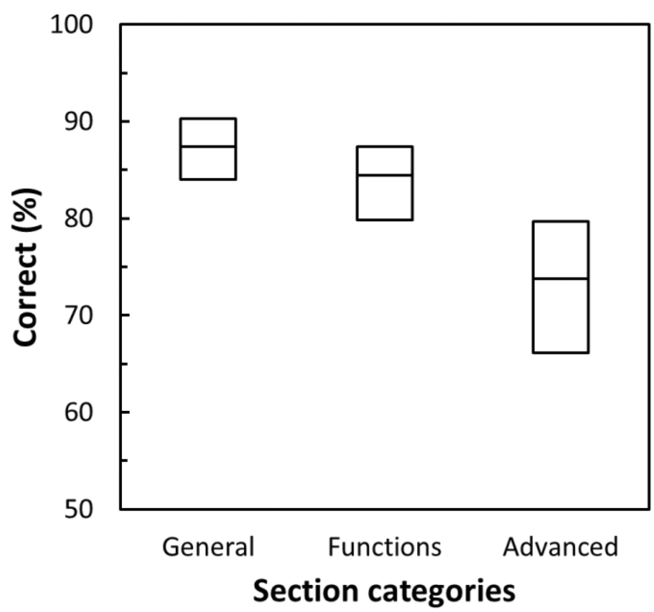

Figure 3. Correct (%) across three cohorts related to section categories of General spreadsheet skills, Functions, and Advanced spreadsheet skills.

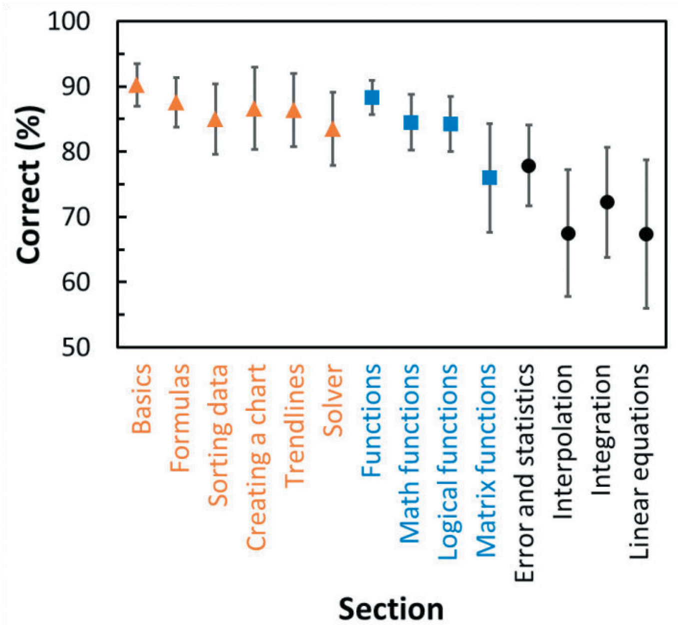

Figure 4. Correct (%) parsed across fourteen sections combining three cohorts. Orange triangles represent General spreadsheet skills, blue squares represent Functions, and black circles represent Advanced spreadsheet skills. Shapes represent mean of all questions in the section, and error bars represent one standard deviation.

Identifying cell locations, distinguishing between stored and displayed content in cells, and creating charts of various types are some of the skills covered in six sections categorized as General spreadsheet skills. Fraction correct was between 83 and 90% on average with standard deviations between 3 and 15% for the 37 question levels in General skills sections (Figure 4 and Supporting Information). The Solver section, including goal seek and solver tools, led to the lowest average correct (83%) in General skills challenge activities. Also, students made 2.5 to 3 attempts before correct for the third quartile in the Solver section, which was the largest attempts of the six General skills sections. For comparison, Basics and Formulas sections both took less than 2 attempts before correct (third quartile), while the percent correct in these two sections was greater than the Solver questions (see Supporting Information). Overall, students correctly answered questions related to General spreadsheet skills at a high percentage while requiring a median of 2 or less attempts before correct for most questions.

Many functions, such as average or standard deviation, are built-in or intrinsic in spreadsheets. Spreadsheet functions allow many calculations to be completed efficiently and without writing lines of code, which decreases the working memory needed to complete large numbers of calculations. Four sections focusing on functions and specific types of functions included 38 question levels (Table 1). With unlimited attempts, average correct varied from 76 to 88% with variation of 2 to 9% by cohort (Figure 4). A Matrix functions section was introduced in 2019 and contained the most challenging questions at 76% average correct. Third quartile attempts before correct was between 1 and 2 for Functions and Logical functions; Math and Matrix function sections took 2 to 2.5 attempts before correct (see Supporting Information). Overall, median correct for Functions sections was 2% lower than General spreadsheet skills and 11% higher than Advanced spreadsheet skills.

Four sections encompass more advanced spreadsheet skills, namely Error and statistics, Interpolation, Integration, and Solving systems of linear equations (Figure 4). The designation 'advanced' summarized spreadsheet computations that may require multiple steps or functions, computations beyond using a standard calculator, and/or mathematics beyond algebra. Median as well as 1st and 3rd quartile fraction correct were all lower for Advanced skills' questions compared to General skills or Functions (Figure 3). Third quartile attempts before correct were about 2 or higher for all sections, which is larger than the other sections (see Supporting Information). Several explanations can elaborate on these findings.

Interpolation involved two challenge activities containing 10 total questions. Median correct on single interpolation calculations were 10 to 22% larger than double interpolation calculations, despite the fact that double interpolation is single interpolation completed multiple times. This observation may identify a cognitive threshold as single interpolation calculations presented 5 numbers of interest while double interpolation questions had 10 numbers. Integration covers numerical integration and definite integration, which presents integrals used in the Material and Energy Balances content. Fraction correct on the integration challenge activities ranged 64 to 72% for individual cohorts (See Supporting Information), which showed struggle for a measurable fraction of the class. Many students were in their first year of college and taking their first calculus class during the same semester, so the lack of familiarity with and mastery of integration is not surprising. Finally, solving systems of linear equations applies content from the Matrix functions section, which showed the lowest average correct for all of the Functions sections. Consequently, solving systems of linear equations questions returned a relatively low average correct of 67%.

Question Type and Order

Having different question types aligns with the multiple representation principle and may engage different learning styles (Felder and Brent 2016; Mayer and Moreno 2002). Different question types show varying fraction correct (Figure 5). Performing ANOVA and pairwise hypothesis tests

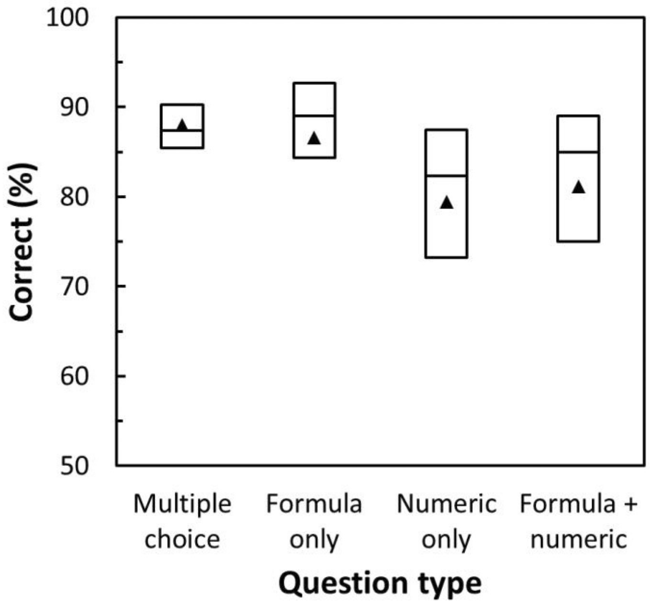

Figure 5. Correct (%) across challenge activities by question type across three cohorts.

across question types finds some statistically significant differences ($F(3, 337) = 13$, $p < 0.0001$, see Supporting Information). Some question types would logically alter the probability of answering correctly with unlimited attempts. Multiple choice questions have a finite number of responses, usually 3 to 6, so even with rolling numbers/content, guessing would eventually lead to the correct answer with unlimited attempts. Next, single numeric responses are common for auto-graded homework in science and engineering, while formula entry is more unique to spreadsheet challenge activities. Finally, multiple responses combining a formula and a numeric response, which are defined as the stored or displayed cell content in the book, provided a more complete understanding of a student's spreadsheet skills than other types of auto-graded assessments. Multiple choice and Formula only as well as Numeric only and Formula + numeric are two pairs of question types that showed statistically similar fraction correct. However, statistically significant differences were quantified for all other pairs of question types. For example, fraction correct on Formula only questions was statistically significantly higher than both Numeric only and Formula + numeric question types. Thus, question type may be a way for question authors to modulate cognitive load or deliberately scaffold questions (Lang 2016; Lape 2011).

Challenge activities were designed to become more difficult as students progressed (Lape 2011), so another hypothesis was that scaffolding, beyond the content expertise of

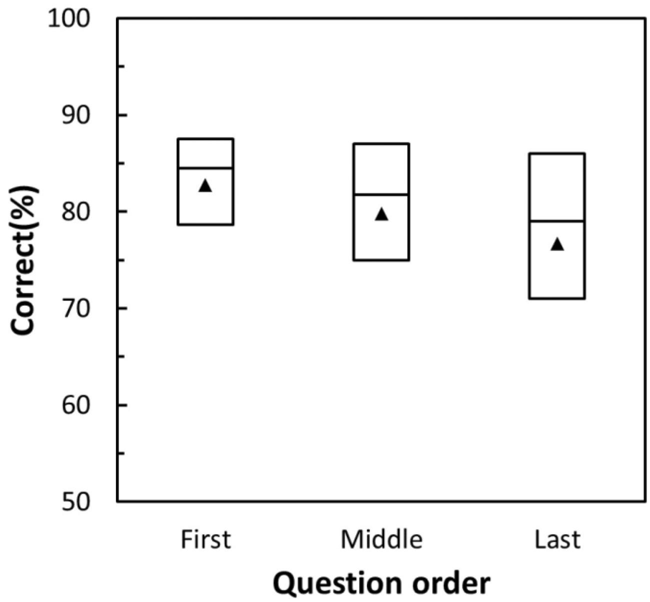

Figure 6. Correct (%) across challenge activities related to spreadsheet skills by question order. The number of questions for first, middle, and last order was 69, 211, and 69, respectively.

the questions' author, could begin to be measured by examining the fraction correct across question order. The median correct decreased from 84 to 79% as the challenge activities progressed from the First to Last question of each activity (Figure 6). Comparing fraction correct showed statistical differences for the three groups ($F(2, 346) = 6.3$, $p = 0.002$). For pairwise comparisons, the First and Middle questions and First and Last questions showed greater statistical differences than Middle and Last questions (see Supporting Information). Overall, stating that auto-graded activities are scaffolded has some justification based on the fraction correct as a function of question order. Using a single metric – fraction correct – to quantify scaffolding is a limitation of the study, and future work on problem difficulty and scaffolding could use multiple expert raters or use validated tools, e.g., NASA Task Load Index (Duckett et al. 2019; Asogwa et al. 2021). Question order will be examined further in the discussion of the Copy sheet button next.

Copy Sheet Button

A hypothesis was that the ability to efficiently copy and paste data from questions into a spreadsheet encouraged deliberate practice and would lead to a higher fraction of questions answered correctly. The addition of a Copy sheet button was in response to student feedback as manually transferring up to 50 cell values to a spreadsheet was onerous. The copying of values in a group of cells is a single action using the Copy sheet button and allows the learner to focus on the functions and formulas needed to complete the question. Students may be encouraged to make subsequent attempts after receiving feedback if transcription errors between the auto-graded questions and a spreadsheet application are not a concern.

The 2020 cohort completed 45 questions across 7 sections containing a new Copy sheet feature (see Supporting Information). Questions including the Copy sheet button included 1 Multiple choice, 18 Numeric only, 10 Formula only, and 18 Numeric + formula questions. Overall, the 2020 cohort used the Copy sheet button over 1,700 times across the 45 question levels (see Supporting Information). An assumption was that each click of the Copy sheet button in the interactive textbook was followed by pasting into a spreadsheet application, but the pasting action could not be monitored at this time. The students used the Copy sheet button when correctly answering over 1,000 questions with 83% of the cohort using the button at least once.

All questions and sections received Copy sheet clicks, but the total number of Copy sheet clicks varied (see Supporting information). Variation was expected as the number of filled cells and calculation complexity changed across the content. Overall, the average number of Copy sheet clicks was 38 per question. The Systems of linear equations and Matrix functions sections received the most Copy sheet clicks per question with over 60. The Copy sheet button was not limited to a single use, so students were able to use the button multiple times if they did not get a question correct on their first attempt.

While the sections that received the most Copy sheet clicks per question were Systems of linear equations and Matrix functions sections, the sections with the most unique student users were Error and statistics and Systems of linear equations sections with over 40% of the students using the Copy sheet button (see Supporting information). Overall, the Copy sheet button was used by an average of 22% of the 2020 cohort in any single section.

Fraction correct was measured across 45 common questions between cohorts (Figure 7). The 2020 cohort showed statistically significant improvement compared to the 2019 cohort on common questions (p = 0.0006 for paired analysis by question). The effect size (Hedges g) was 1.3, which is large. Therefore, the hypothesis that the Copy sheet button made making multiple attempts more efficient and increased fraction correct is supported statistically. More specifically, median correct improved by 3%, while 1st quartile correct for the 2020 cohort increased by 6% from the 2019 cohort. Thus, the Copy sheet feature may assist students in the bottom quarter of the class more than the middle half similar to (Edgcomb and Vahid 2014), but paired analysis by student was not performed.

Improvements in fraction correct between cohorts in five of the seven sections were measured (see Supporting Information). Significant improvements were measured in the Integration section

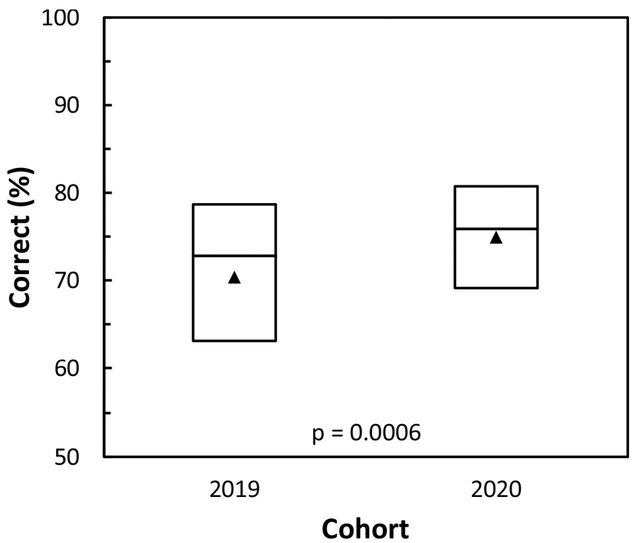

Figure 7. Correct (%) on questions that included the Copy sheet button. The 2019 cohort did not have a Copy sheet button, while the 2020 cohort could use the Copy sheet button without penalty.

where all 10 questions showed improvements averaging 14% and ranging from 8 to 28%. Systems of linear equations also saw noteworthy improvements, which are detailed next.

The Systems of linear equations section served as a case study on the use of the Copy sheet button. Fraction correct varied across the six question levels and between the two cohorts (Figure 8). The first two questions showed a similar fraction correct (within 5%). These two questions received just 15 and 6 total Copy sheet clicks, respectively, which was a low usage. While the number of filled cells for the first two questions was around 18, the questions did not require the use of spreadsheet functions to solve. Thus, the first two questions do not address the hypothesis directly.

The final four problems showed 10 to 14% increase in fraction correct between the 2019 and 2020 cohorts when performing spreadsheet calculations on 15 to 20 cells simultaneously. Each of these four questions received over 75 total Copy sheet clicks, i.e., seven times more usage than the first two question levels. Over 50% of students in the 2020 cohort used the Copy sheet feature for these four questions. In the authors' experience, many handheld calculators are not capable of solving systems of linear equations, so using a spreadsheet makes solving these types of problems much easier. Overall, the measurable increase in fraction correct is greater than cohort to cohort variation and should at least in part be attributed to the Copy sheet button. Thus, the Copy sheet button increased engagement in

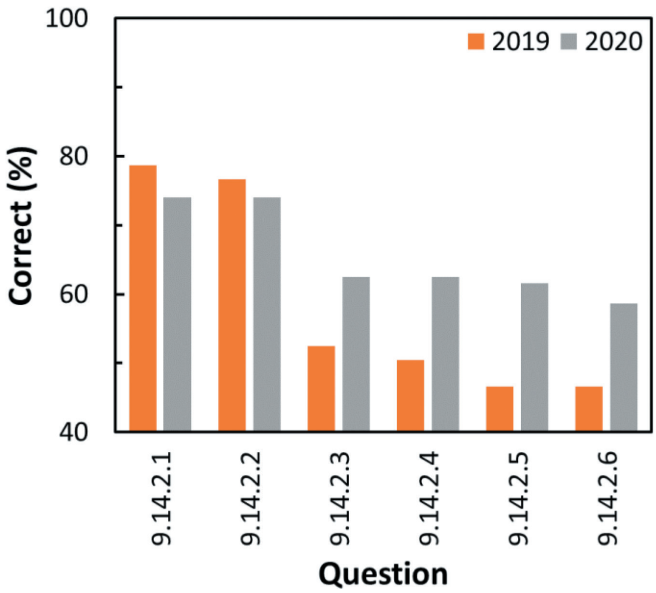

Figure 8. Correct (%) on six questions related to Systems of linear equations. The Copy sheet button was only offered to the 2020 cohort.

problem solving by decreasing the effort needed to translate 10 or more cell values to a spreadsheet, which allowed students to focus on successfully answering the question at hand.

Two additional correlations further quantify that increased usage of the Copy sheet button led to more questions being answered correctly. First, as the number of students who used the Copy sheet button increased, the change in cohort fraction correct showed a positive correlation (see Supporting Information). The Pearson correlation coefficient was 0.34, which indicates a moderate, positive linear correlation (Evans 1996). For questions with at least 10 students using the Copy sheet button, 81% of the questions saw an increase in the fraction correct up to 28%.

Students in the 2020 cohort who used the Copy sheet button more often completed more questions successfully (see Supporting Information). A total of 80 students in the 2020 cohort used the Copy sheet button with 74% using the button more than 10 times. On one hand, 13% of students (2 out of 16) were able to complete all 45 questions with the Copy sheet button without using the button. On the other hand, 55% of students (44 out of 80) who used the Copy sheet button at least one time were able to correctly complete all of the questions. The Pearson correlation coefficient between correct and total clicks was 0.47, which indicates a moderate and nearing a strong, positive linear correlation between two variables (Evans 1996). Overall, students using the new Copy sheet button were more successful on completing the challenge activities than non-users.

CONCLUSION

Quantifying students' spreadsheet skills using an interactive textbook included over 100 auto-graded questions with rolling numbers and cell locations included three cohorts of students. These auto-graded questions are a form of deliberate practice by combining feedback on correctness, providing solutions and explanation, and allowing unlimited attempts. While median correct was high, i.e., between 94 and 99% without statistically significant differences between cohorts, the fraction correct varied between 67 and 90% across the 14 sections of content. Also, fraction correct varied logically by question type as well as question order, which aligned with theories related to scaffolding and the multiple representation principle.

The use of a new Copy sheet button tested a hypothesis related to deliberate practice. More than 1,700 clicks over 45 questions resulted in increases up to 28% in fraction correct compared to a previous cohort, which were statistically significant increases with large effect size. Overall, continuing to explore the deliberate practice using interactive technologies shows promise to improve current technologies and build new learner-centered tools.

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DECLARATION OF INTEREST

One of the authors may receive royalties from sales of the zyBooks detailed in this paper.

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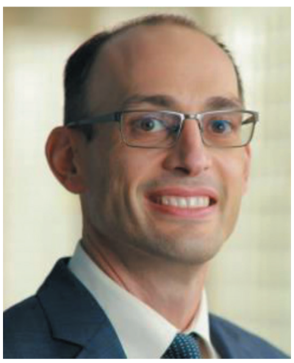

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Supporting information for:

Deliberate practice of spreadsheet skills when using copiable, randomized, and auto-graded questions within an interactive textbook

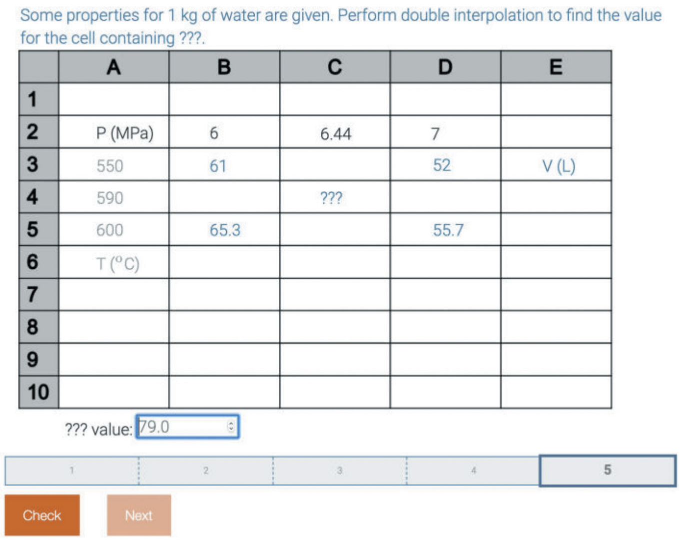

Figure S1. Previous format of auto-graded spreadsheet question related to linear interpolation. Fifth of five question levels. Can be compared to Figure 1 where the Copy sheet button was added.

Table S1. Reading participation (%) for students across* Spreadsheets Essentials *across three cohorts.

Year	2018	2019	2020	All
Median	100	100	100	100
Quartile 1	100	98.6	99.3	99.3

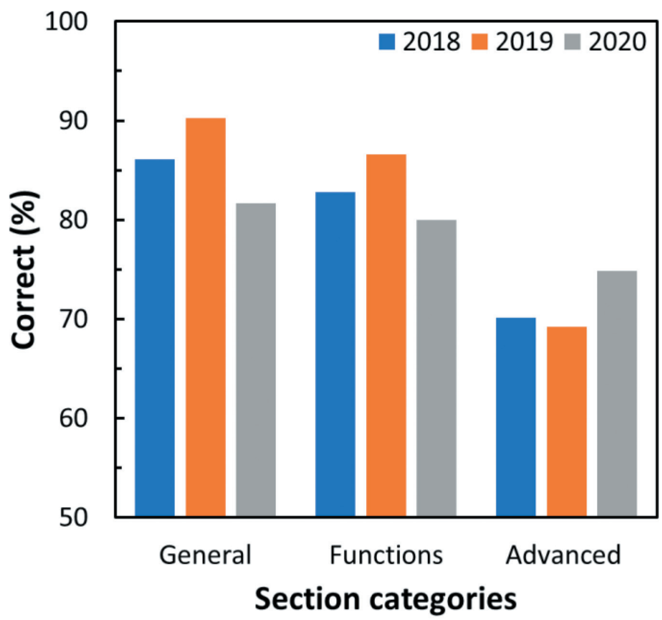

Figure S2. Correct (%) per challenge activities per cohort related to section categories of General spreadsheet skills, Functions, and Advanced spreadsheet skills.

Table S2. Statistical p-values comparing challenge activities within section categories.

	General	Functions	Advanced
General	–	<0.0001	<0.0001
Functions	<0.0001	–	<0.0001
Advanced	<0.0001	<0.0001	–

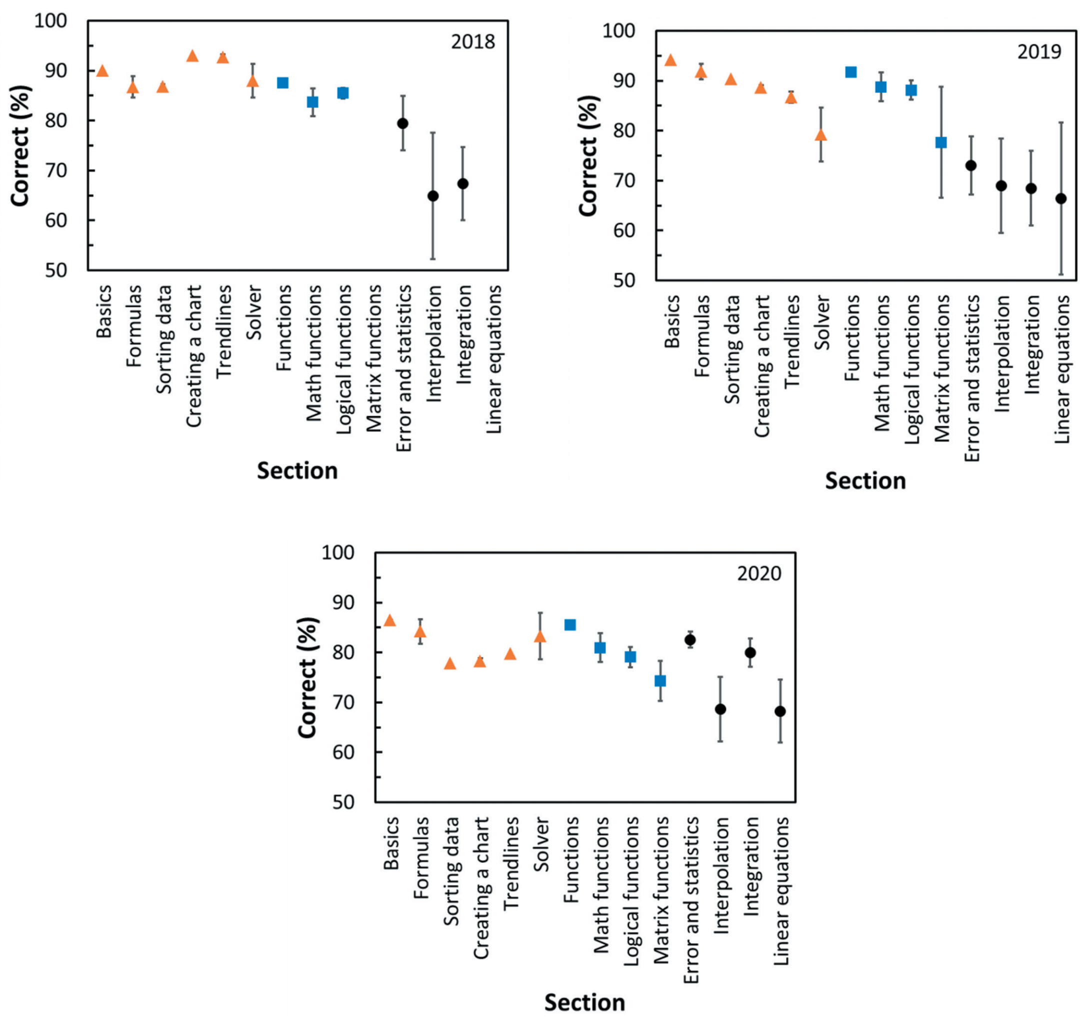

Figure S3. Correct (%) for students across 100+ challenge activities related to spreadsheets parsed into fourteen sections for the 2018, 2019, and 2020 cohorts. Orange triangles represent General spreadsheet skills, blue squares represent Functions, and black circles represent Advanced spreadsheet skills. Shapes represent mean, and error bars represent one standard deviation.

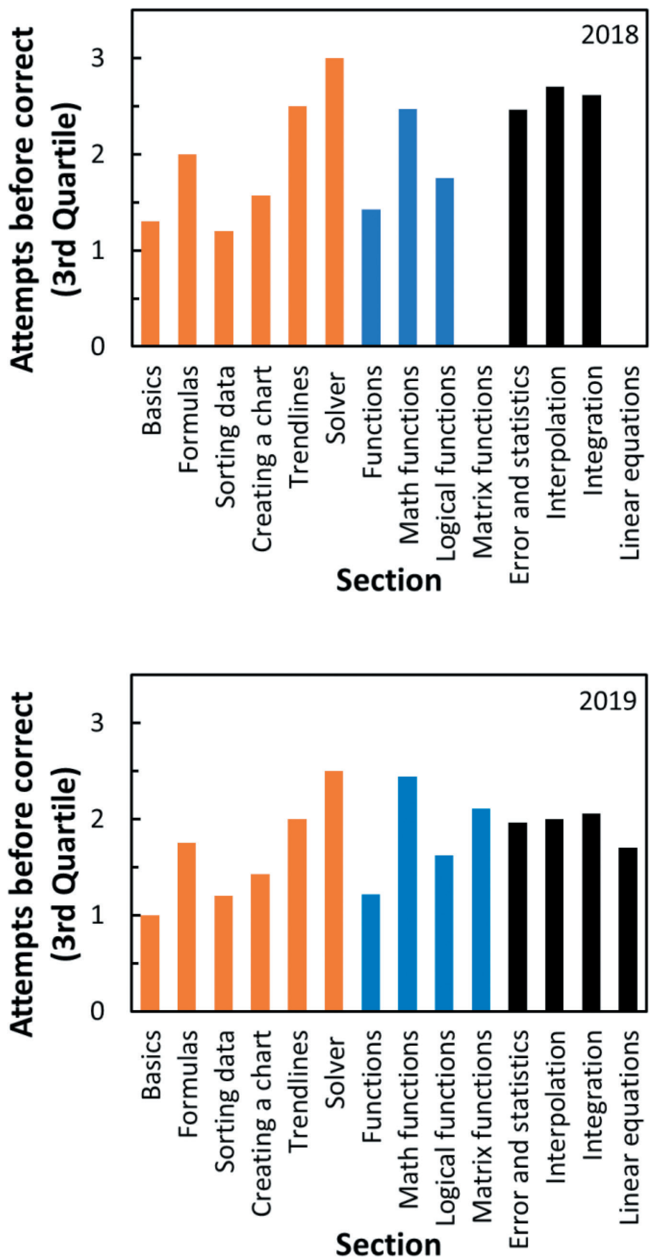

Figure S4. Third quartile attempts before correct for students across 100+ challenge activities related to spreadsheets parsed into fourteen sections for the 2018 and 2019 cohorts. The first six sections represent General spreadsheet skills, the next four sections represent Functions, and the final four sections represent Advanced spreadsheet skills.

Table S3. Median attempts before correct for students across 100+ challenge activities related to spreadsheets parsed into fourteen sections for the 2018 and 2019 cohorts. The first six sections represent General spreadsheet skills, the next four sections represent Functions, and the final four sections represent Advanced spreadsheet skills.

Section	2018	2019
Basics	1.0	1.0
Sorting data	1.0	1.0
Creating a chart	1.0	1.0
Trendlines	1.3	1.3
Formulas	1.4	1.3
Solver	2.0	1.5
Functions	1.0	1.0
Logical functions	1.1	1.1
Matrix functions	–	1.4
Math functions	1.6	1.6
System of linear equations	–	0.9
Interpolation	1.7	1.2
Integration	1.7	1.2
Error and statistics	1.8	1.2

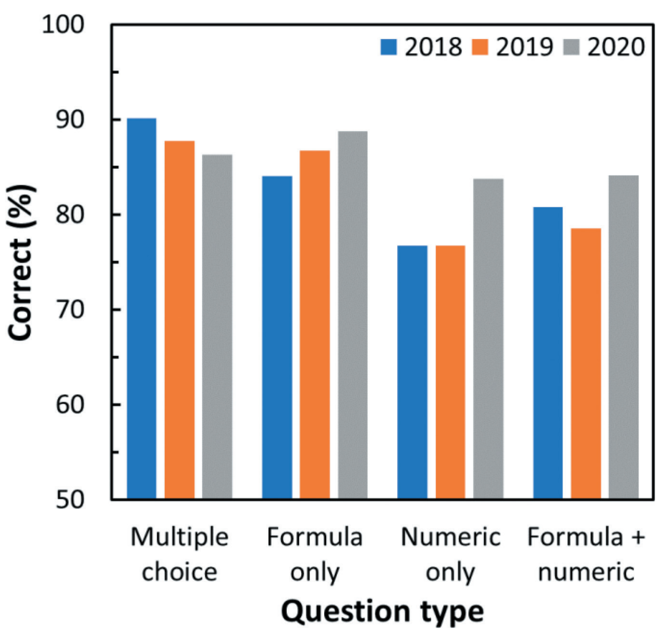

Figure S5. Correct (%) for students over 100+ challenge activities related to spreadsheet skills by question type for three cohorts.

Table S4. Statistical p-values for question type data.

	Multiple choice	Formula only	Numeric only	Formula + numeric
Multiple choice	–	0.23	<0.0001	0.0002
Formula only	0.23	–	<0.0001	<0.0001
Numeric only	<0.0001	<0.0001	–	0.22
Formula + numeric	0.0002	<0.0001	0.22	–

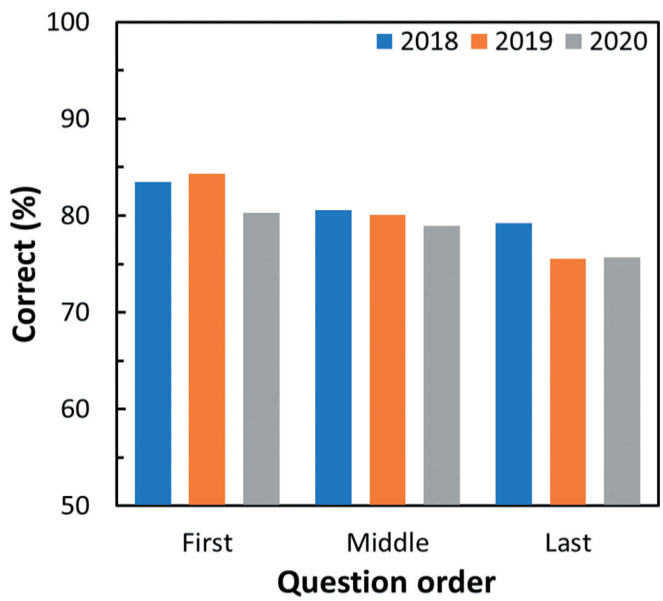

Figure S6. Correct (%) for students across 100+ challenge activities related to spreadsheet skills by question order for three cohorts.

Table S5. Statistical p-values by question order.

	First	Middle	Last
First	–	0.01	0.0007
Middle	0.01	–	0.06
Last	0.0007	0.06	–

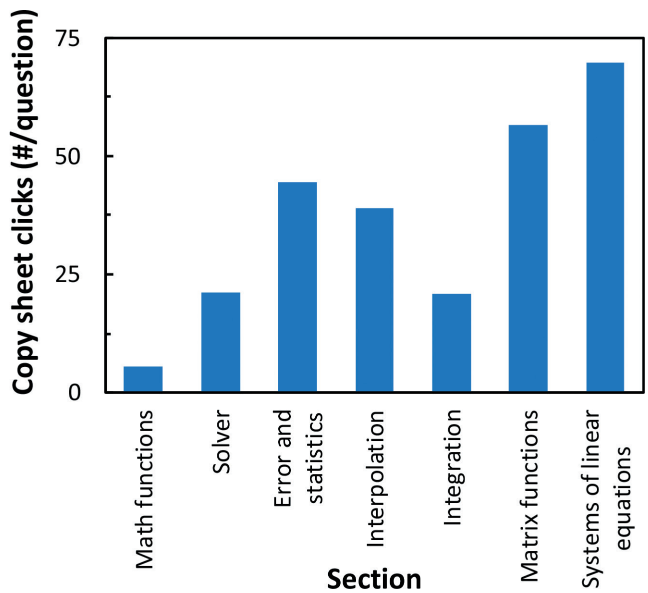

Figure S7. Copy sheet clicks per question across seven sections that offered the Copy sheet button.

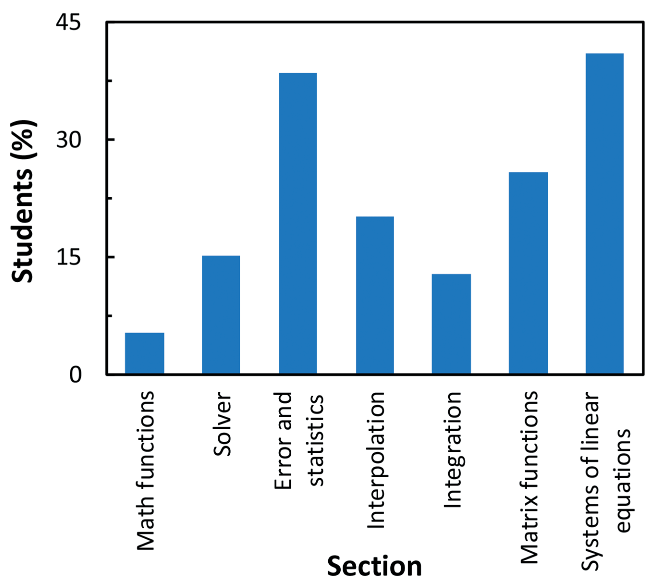

Figure S8. Student utilization rate across seven sections that offered the Copy sheet button.

Table S6. Total number of questions, clicks, and student users for new Copy sheet button for the 2020 cohort.

Section	Questions	Total Copy sheet clicks	Total student users
Math functions	3	17	15
Solver	4	85	58
Error and statistics	5	223	185
Interpolation	10	390	194
Integration	12	251	148
Matrix functions	7	396	173
System of linear equations	6	418	236

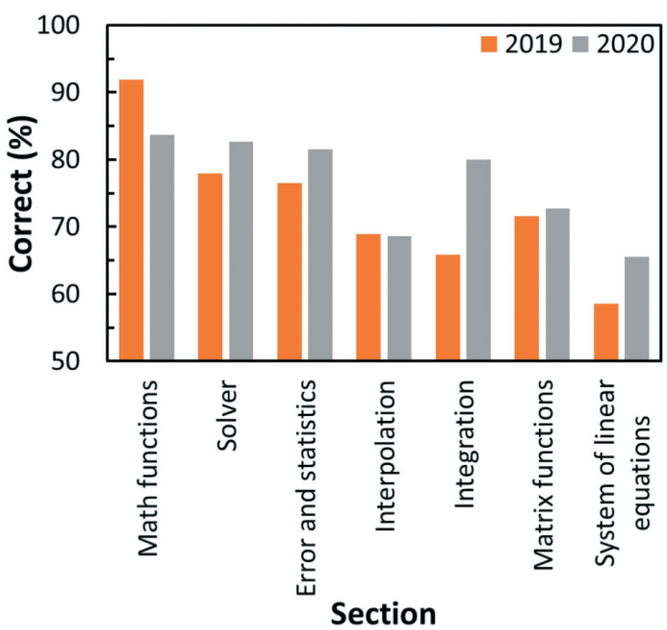

Figure S9. Correct (%) on questions that included the Copy sheet feature. The 2019 cohort did not have a Copy sheet button, while the 2020 cohorts could use the Copy sheet button without penalty.

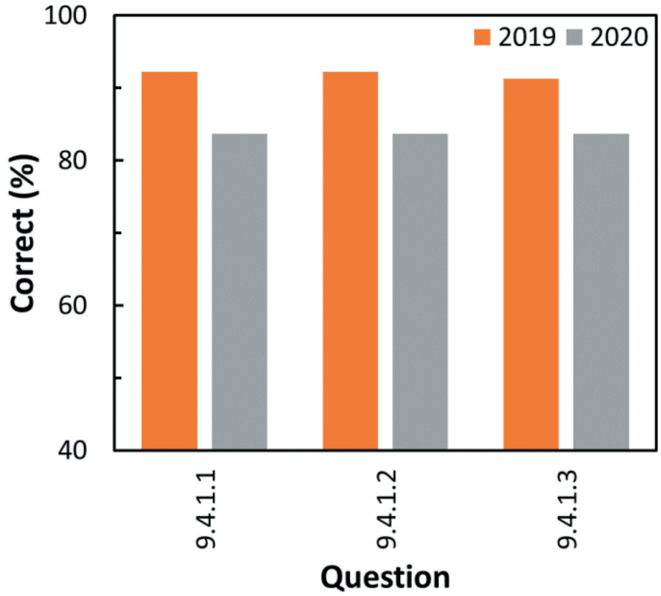

Figure S10. Correct (%) on questions covering Math functions. The Copy sheet button was only offered to the 2020 cohort as it was a newly added function.

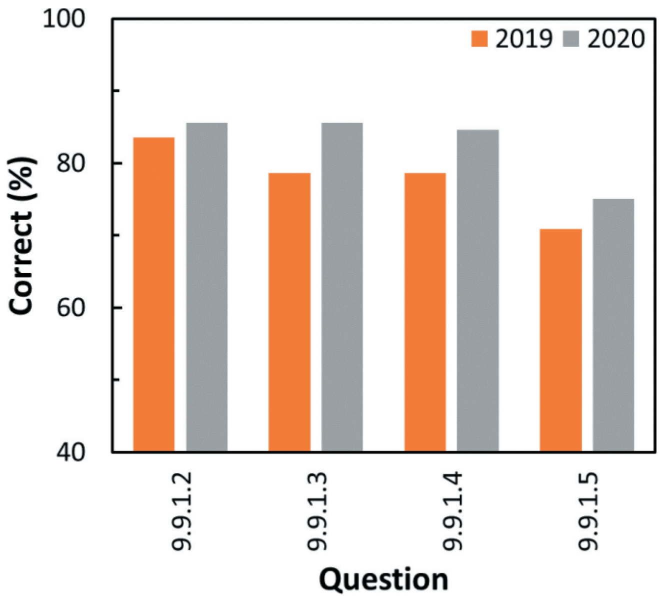

Figure S11. Correct (%) on questions covering Solver. The Copy sheet button was only offered to the 2020 cohort as it was a newly added function.

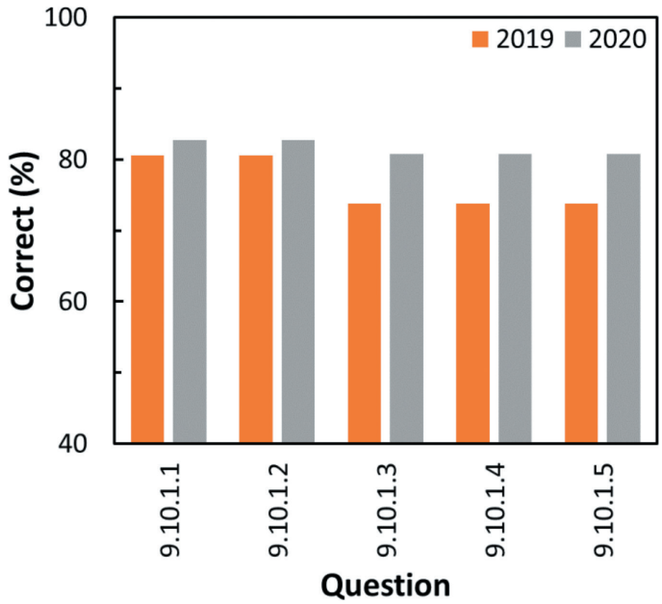

Figure S12. Correct (%) on questions covering Error and statistics. The Copy sheet button was only offered to the 2020 cohort as it was a newly added function.

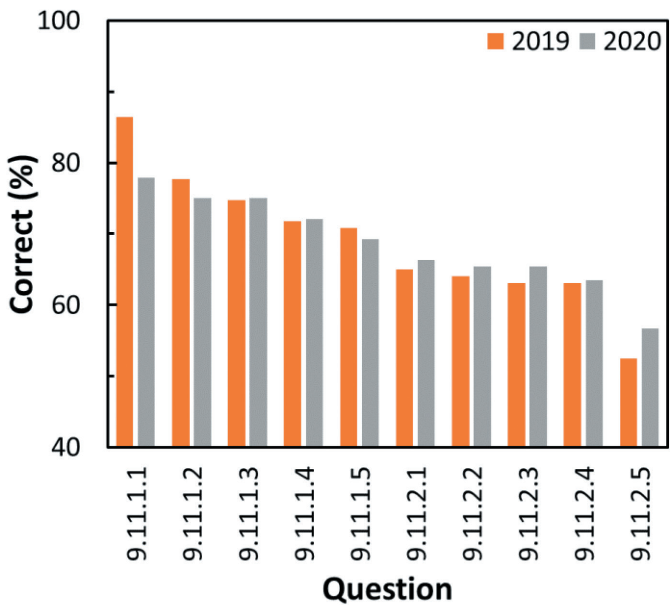

Figure S13. Correct (%) on questions covering Interpolation. The Copy sheet button was only available to the 2020 cohort.

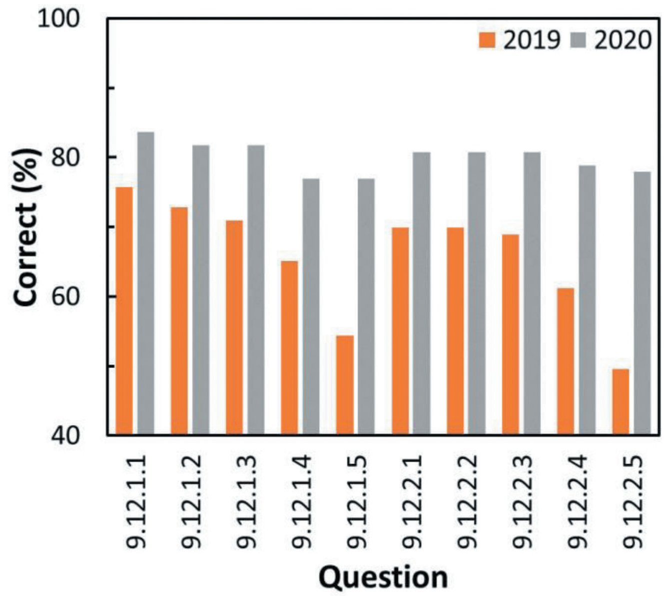

Figure S14. Correct (%) on questions covering Numerical Integration. The Copy sheet button was only available to the 2020 cohort.

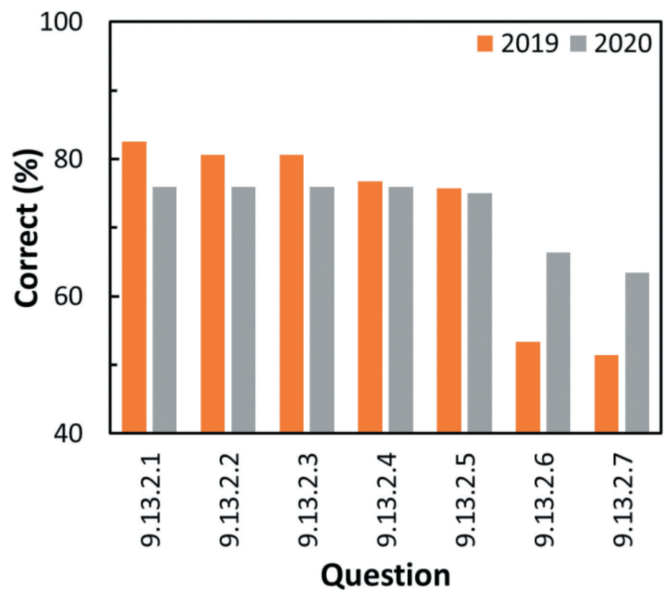

Figure S15. Correct (%) on questions covering Matrix functions. The Copy sheet button was only offered to the 2020 cohort as it was a newly added function.

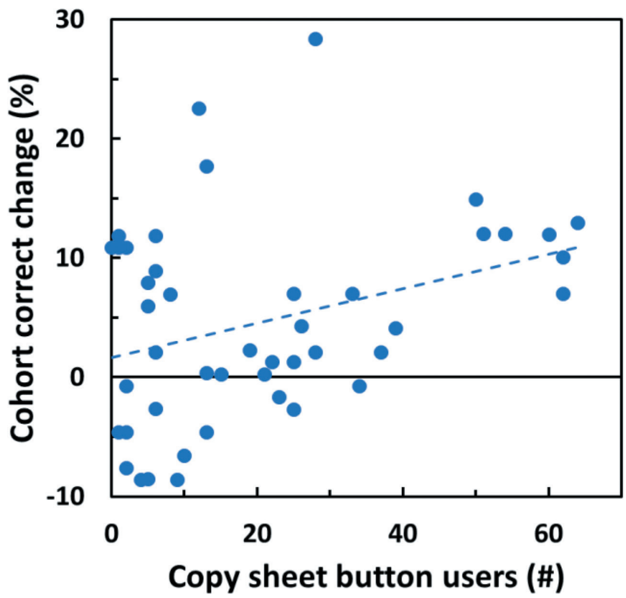

Figure S16. Percent change in fraction correct between 2019 and 2020 cohorts as a function of the number of Copy sheet button users on each question. 45 questions (blue circles) were common between the cohorts. The trendline visualizes a positive linear correlation.

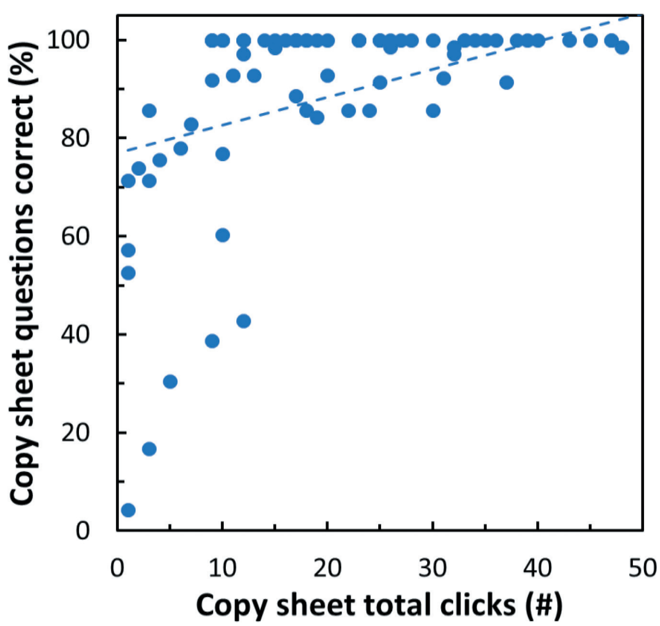

Figure S17. Fraction correct by student for questions with Copy sheet button as a function of the total number of Copy sheet clicks per student (n = 80; subset of 2020 cohort).