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# Reading participation and assessment of spreadsheet skills across multiple cohorts when using an interactive textbook

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## Abstract

This evidence-based practice complete paper centers on the topics of assessment and learning technology for first-year engineering students. Spreadsheets are convenient for completing many calculations that engineering students and practicing engineers encounter. Spreadsheet programs are easily accessible and have been available for decades, including Microsoft Excel and Google Sheets; numerous formulas, functions, and other tasks are common across platforms. However, learning spreadsheet skills is usually limited to demonstration by an expert, such as numerous videos on YouTube. Here, an interactive textbook provided students the opportunity to acquire spreadsheet skills by performing spreadsheet actions. Various components of the interactive textbook apply learning theories including cognitive load, scaffolding, and deliberate practice. First, reading participation measured clicks from using interactive components, including multi-step animations, multiple-choice questions, and matching exercises. Next, students had unlimited attempts to correctly answer over 120 auto-graded, randomized problems. In addition to basic spreadsheet skills and functions, advanced topics included solver, error, statistics, and matrix operations. In total, data generated by five cohorts (> 400 students) were studied. Median reading participation was very high - over 96% of 290 clicks per student - for all five cohorts. In addition, animation view rates were as high as 118%, indicating repetitive use. Animation view rates were higher for more advanced topics, such as double interpolation, compared to the basic skills and formulas. A median completion over 94% on auto-graded problems was observed for each of the five cohorts. By examining fraction correct on specific topics, real-time misconceptions and struggle can be noted by instructors, which leads to opportunities to provide interventions and facilitate learning.

## Introduction

Engineers, students, and other professionals use spreadsheets daily. Common tasks include organizing data, simple and complex mathematical calculations, and creating visuals from charts to dashboards. These skills are common in a rapidly changing world that relies on data analytics and other big data tools to make decisions, create products, and many other tasks. Specific to engineering education, spreadsheets are used across the undergraduate curriculum and commonly introduced in first year courses [1-4].

Spreadsheet applications are used across platforms from phones to multi-core computers with options including Microsoft Excel, Google Sheets, Apple Numbers, and Apache OpenOffice Calc. While books, recorded video courses, and in-person workshops provided training on spreadsheets for decades, web-based materials are now ubiquitous [5, 6]. Millions of videos on YouTube explain how to use spreadsheets, and new videos are being created regularly that are of professional quality by influencers including Leila Gharani and Kevin Stratvert [7, 8]. However, learning new skills beyond a single use normally requires feedback, which in-person lectures or online videos rarely deliver.

The master-student demonstration framework for spreadsheet training is also employed in many engineering courses [9]. For example, sessions held in computer labs involve a professor or teaching assistant demonstrating spreadsheet skills or techniques that can be mimicked by students. While instructors can give real time feedback in computer laboratories with small numbers of students, measuring students' spreadsheet skills at scale is quite difficult. Alternatively, multiple choice tests can assess spreadsheet skills [10]. Now, web-based platforms can deliver interactive content delivery and auto-graded practice at scale.

Thus, interactive textbooks can connect web-based tools, active learning, and sound learning theories, even for spreadsheets [11-13]. Interactive textbooks apply learning theories including visuals, chunking, and regular interactivity. Animations are a visual, step-wise tool to transform static equations and figures into constructive activities that can stimulate short- and long-term memory creation [11, 14]. By parsing content into smaller activities, in both animations, multiple choice questions, and matching exercises, the tenets of cognitive load theory are applied [11, 15-17]. Clicking, dragging, and typing engages the learner throughout an interactive textbook, which aligns with the multiple representation principle [18].

Textbook reading can be measured using self-reported surveys or from reading quizzes. However, textbook reading is not widely documented, especially in first year engineering courses. In general, higher education reading rates between 20 and 50% have been documented [12, 19, 20]. However, student responses to interactive engineering textbooks have shown high engagement, such as median reading rates up to 99% [21-24]. Reading rates in interactive books involve capturing clicks in the content, including animations and learning questions. Specifically related to spreadsheets, thousands of student interactions were collected, and at least 75% of students completed 100% of the reading participation activities by the due date [25, 26].

Beyond the learning theories related to interactive content, the framework of deliberate practice applies for the auto-graded problems of interest. Defined and repetitive practice, feedback on correctness, explanation of errors, and availability of repeated formative activities are some of the pillars of deliberate practice [27-29]. Advancing to more difficult content is another tenet of deliberate practice, commonly called scaffolding. Scaffolding activities intentionally move from simpler to more complex and has shown improvements to long-term memory by reducing load on working memory [30] and self-regulation via multiple attempts [31].

Auto-grading of spreadsheets has recently been discussed [2, 25, 32]. Auto-grading provides immediate feedback when learning spreadsheet skills and has potential to save time for faculty, teaching assistants, and graders. The challenges of assessing both formulas and the outputs of formulas in a spreadsheet is analogous to both grading code and the output of the code [33].

The field of learning analytics is expanding and examines how quantitative metrics generated by students align with learning theories. Specifically, clicks create reading participation scores and multiple metrics quantify students' activity on auto-graded problems. Similar metrics were established in previous work and are expanded here [25, 26, 34, 35]. In addition, this contribution will examine reproducibility across several cohorts, a topic rarely discussed in ASEE proceedings. Overall, the research questions presented below apply for the first-year engineering students generating the data as well as more broadly, which could include any science, technology, engineering, or math (STEM) students or even middle and high school students creating their first spreadsheets.

## Materials and Methods

An interactive book from zyBooks – a Wiley brand – is available under the standalone title *Spreadsheet Essentials* or as single chapter of the *Material and Energy Balances* zyBook [36, 37]. All activities by students, faculty, and learning assistants are completed within any HTML5-compliant browser without additional applications. Content is divided into sortable sections, and three topical categories will help organize the data and discussions (Table 1). Two sections were added in 2023, namely Lookup Functions and Date and Time Functions, which are not included in the data presented here.

**Table 1. Categorized sections from *Spreadsheet Essentials* zyBook as of February 2023.**

| General skills | Functions | Advanced skills |
|---|---|---|
| Spreadsheet basics | Spreadsheet functions | Error and statistics |
| Formulas | Math and trigonometry | Interpolation |
| Sort and filter | Logic and counting | Integration and numerical integration |
| Charts | Matrix | Systems of linear equations |
| Trendlines | Lookup | |
| Solvers | Date and time | |

Sections were authored based on several established learning theories as discussed in previous publications [25, 26, 34]. Content is written in chunks to align with cognitive load theory [11, 16, 17]. The normal format of a section includes definitions, demonstration through multi-step animations, learning questions to provide conceptual details, and auto-graded problems to apply the new content. The search menu allows terms to be quickly found upon returning to the book. Over 50 animations demonstrate spreadsheet skills in 3 to 6 steps; each step requires the reader to click and advance the animation. Viewing animations aligns well with human's attention span, i.e., less than 2 minutes [38]. Learning questions, including multiple choice, true/false, and matching, are designed for immediate feedback and backward fading [39]. Finally, auto-graded questions are called challenge activities. This type of online homework instantly grades students' entries. For spreadsheet problems, both numbers and cell locations randomly change with every attempt with most problems having thousands of versions. Some auto-graded questions are multiple choice, while most problems ask for one or more numeric responses, spreadsheet formulas (graded as a string), or a combination of numeric and formula entry. Both learning questions and challenge activities were written to be scaffolded with easier questions followed by more difficult questions [12].

For brevity and to focus on the data being presented, no screenshots of animations or auto-graded problems are included here. Previous publications include example images [25, 26, 34], and faculty can obtain free evaluation copies through the publisher's website [37]. Reading participation in the interactive textbook involves documenting clicks completed before the due date; clicks can include moving through steps of an animation, answering true/false or multiple-choice learning questions, or completing matching exercises. Overall, more than 290 clicks were required to complete reading participation of the 14 interactive spreadsheet sections. Also, fraction correct on over 120 auto-graded questions, which are called challenge activities, was also recorded. Students can make unlimited attempts without penalty. Unless noted, all data are collected at the due date of the assigned section(s).

Students from five cohorts at a public research university generated the data presented here. Cohorts during the Spring semester of 2018, 2019, 2020, 2021 and 2022 included 98, 98, 94, 66, and 57 students, respectively. Students withdrawing from the course were not included in the analysis, which differs from some previous work [25]. The majority of the students were in their first year (freshman) majoring in either chemical engineering or environmental engineering. The data are presented in aggregate for one or more cohorts, which may be a limitation as the diversity of the individual learner is lost. The modality of the 2018, 2019, and 2022 cohorts was in person. The 2020 cohort was partially in person and partially remote synchronous, and the 2021 cohort was a fully remote synchronous course. The use of the interactive textbook for reading participation and challenge activities was consistent, and thus, independent of modality; further quantification is included in another contribution to this conference [40].

The spreadsheet content accounted for 1 of 9 chapters covered during the course in material and energy balances; the course introduces students to engineering problem solving as well as material and energy balances in both non-reactive and reactive processes. Discussion of material and energy balance textbook analytics are available in other publications as well as other contributions to this year's ASEE conference [23, 24, 41]. Spreadsheet content was included in several assignments as needed throughout the semester, and spreadsheet use was encouraged when solving energy balance problems during the last month of the semester.

Students were awarded up to 5% each for reading participation and auto-graded challenge activities for their final course grade for assignments related to all 9 chapters. A forgiveness factor of 15 incomplete/incorrect auto-graded questions (out of ~500 assigned questions) was used based on educational best practices, but the data presented here are uncorrected. Previous spreadsheet instruction or experience was not measured. Positive student feedback related to the interactive textbook was reported earlier and will not be discussed here [23, 24].

Aggregating multiple data sets are represented as box plots to capture multiple metrics, namely 1$^{st}$ quartile, median, and 3$^{rd}$ quartile. Box plots ignore outliers that skew mean values. However, mean values may be included to help quantify skewness. Hypothesis testing was completed. Performing t-tests generates p values, and statistical significance noted when $p < 0.05$. Data generated by students can lead to nonnormal distributions. However, t-tests are still acceptable with large data sets ($n > 20$) [42, 43].

## Results and Discussion

Data from over 400 students who performed over 100,000 reading clicks and attempted over 40,000 auto-graded questions are analyzed here. This quantity of student data related to spreadsheet skills is new and unique. First, student engagement is measured across 5 cohorts, which quantifies the reproducibility of reading participation. Next, the tenets of deliberate practice from using auto-graded spreadsheet problems examine how immediate feedback and multiple attempts vary with the different spreadsheet topics covered in the interactive textbook. Overall, the many evidence-based practices introduced earlier provide both framing for and explanation of the large data sets presented here.

*Does reading participation vary by cohort?*

High reading participation was observed for all cohorts (**Figure 1**). The median reading participation was 100% for 4 of the 5 cohorts; a decrease to 97% median reading participation was observed in 2019. First quartile reading rates were between 95 and 100%, except for the 2021 cohort. In 2021, a first quartile reading participation of 73% was measured. This cohort was the only group to be fully instructed using a remote synchronous modality due to the COVID-19 pandemic. The difference in modality may account for the relatively wide distribution of reading participation. As presented in the introduction, higher education reading rates are rarely reported above 50% [12, 19, 20], and little data related to spreadsheet education or training is published. Thus, these reading participation results provide new data on student engagement related to spreadsheet learning.

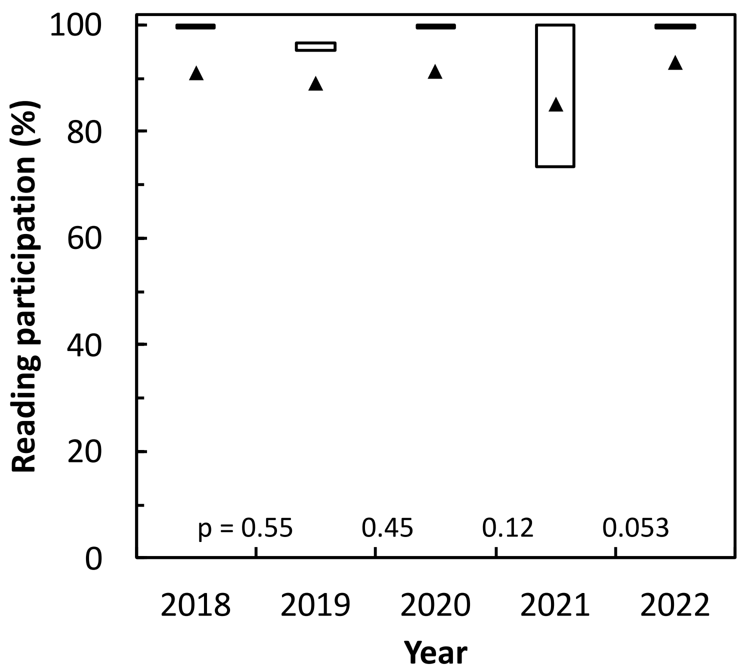


**Figure 1. Reading participation for spreadsheet content in an interactive textbook as a function of five cohorts (n = 413 students). Median and interquartile range are included for all cohorts; triangles indicate mean. p-values compare consecutive cohorts.**

Beyond quantifying engagement with the interactive textbook, cohort to cohort variation can be measured and quantify reproducibility. Hypothesis tests between pairs of cohort as well as ANOVA analysis compared reading participation between cohort. No statistical significance was found between cohorts ($p > 0.05$). Therefore, providing a small grade incentive (5% of total course grade) led to high, reproducible reading participation. Overall, interactive textbooks provide a viable, reproducible technology to engage students with new spreadsheet concepts and content.

Viewing animations are one component of the reading participation. View percentages capture watching all steps of an animation divided by the number of students; animation views can occur at any point during the term, which differs from the reading participation presented earlier. View percentages equal to and greater than 100% were observed, which indicates students re-watch all steps of the animation at some point during the semester [44, 45]. While the most watched animations vary from cohort to cohort, the most watched animations in aggregate are tabulated here (**Table 2**). For example, the most watched animation reported for the 2018 cohort (titled Formulas using $) is not included in the most viewed animations when aggregated across five cohorts [26]. Despite animations being present in 14 different sections, three of the top five animations come from a single section.

**Table 2. Five most viewed spreadsheet-related animations in an interactive textbook when aggregated across five cohorts totaling 413 students.**

| Animation Title | Section Title | View (%) |
|---|---|---|
| Using MINVERSE spreadsheet function | Matrix functions | 118 |
| Double interpolation in the spreadsheet | Interpolation | 111 |
| Linear interpolation in a spreadsheet | Interpolation | 106 |
| Calculations of a least squares fit | Solvers | 106 |
| Visualizing linear interpolation | Interpolation | 104 |

The section covering interpolation accounted for three of the top five in animation views. The interpolation section's reading participation and auto-graded problems were assigned in parallel with reading about and solving problems related to steam tables, which is a widely discussed topic when teaching thermodynamics [46]. All three animations in this section were in the top five list. The necessity to perform interpolation and double interpolation both as part of the spreadsheet content and again while solving other engineering problems related to steam tables may provide some explanation for this topic's popularity. The ability to estimate properties, which is analogous to interpolation, is a topic that engineering students may feel uncomfortable with and provides additional rationale for these findings [47].

The other two most watched animations cover topics that align well with the strengths of spreadsheets. The most watched animation comes from the matrix functions section and using the MINVERSE function, which takes the inverse of a matrix. This animation's high view rates was surprising to the authors for several reasons. First, the matrix functions section is normally assigned and due during the final week of the semester, which does not allow weeks for students to return to rewatch/review this content. Second, the application of matrices to solve systems of linear equations is aligned with solving many engineering problems in the course. However, students are not required to use matrices on homework or assessments, i.e., quizzes and exams, since algebra is usually effective and efficient for solving problems in this course. Finally, calculations of a least squares fit is part of a section covering goal seek, solver, and fitting models to data. While this topic exemplifies the utility of spreadsheets to quickly fit a line to given or measured data points, this concept is not core to the course's learning objectives and is not applied in other assignments for the course. However, this content may be useful for other courses that the students are taking, namely chemistry and physics laboratories.

Overall, reproducible, significant reading participation was measured over five cohorts, which quantifies how technologies like interactive textbooks can bring active learning to pre-class activities.

*Does fraction correct on auto-graded problems vary by cohort?*

Moving beyond effort-based reading participation, auto-graded problems examine students' ability to complete spreadsheet tasks, including write formulas and complete computations with spreadsheet functions. Historically, this type of formative assessment for spreadsheets would require one or many instructors to examine individual spreadsheets. Now, the pillars of deliberate practice, including scaffolded, randomized exercises allowing multiple attempts, can provide students immediate feedback on the spreadsheet skills. Fraction correct captured the questions being correctly answered before the due date, independent of the number of attempts before answering correctly. Median correct was very high varying from 94 to 99% across the cohorts (**Figure 2**). The 2020 cohort had the highest median and first quartile correct, which may be related to the new Copy sheet button feature [25] and/or the additional screen time during lockdowns. The first quartile correct varied from 66 to 87%. Thus, three quarters of the students exhibited proficiency completing spreadsheet tasks across all sections. Hypothesis tests and ANOVA analysis comparing the fraction correct across cohorts found no statistically significant differences.

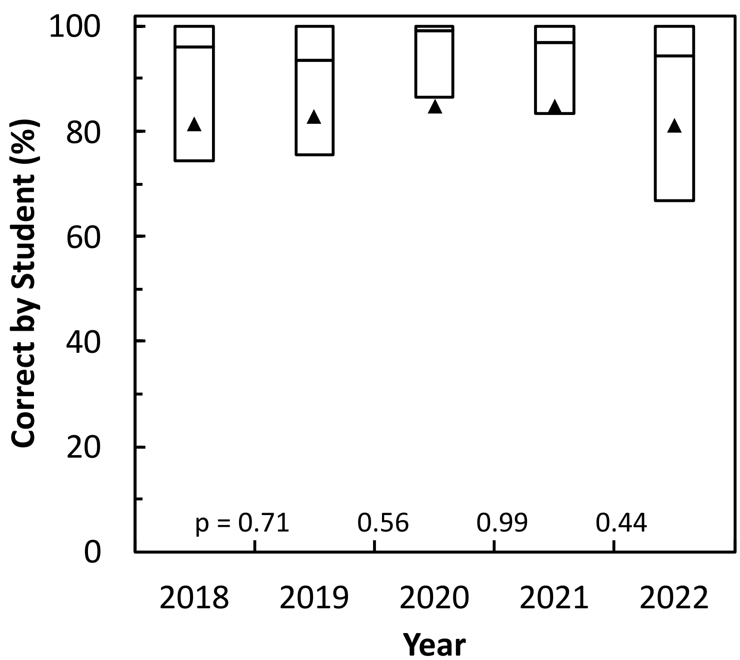


**Figure 2. Percent correct on auto-graded problems related to spreadsheets in an interactive textbook as a function of five cohorts (n = 413 students). Median and interquartile range are included for all cohorts; triangles indicate mean.**

*Do fraction correct and attempts vary across spreadsheet topics?*

The mean correct across all sections and students was 83% with a standard deviation of 15% (Figure 3). Three categories organized the sections for further discussion covering general spreadsheet skills, functions, and advanced spreadsheet skills. The mean correct General Skills and Functions categories were relatively close at 88% and 86%, respectively. However, the Advanced Skills lead to a measurably lower mean of 76%. The distribution of fraction correct was captured by using the standard deviation across individual question levels in each section. General Skills and Function categories had similar, modest standard deviations of 8% and 9%, respectively, while Advanced Skills had much larger standard deviation (23%) for these four sections.

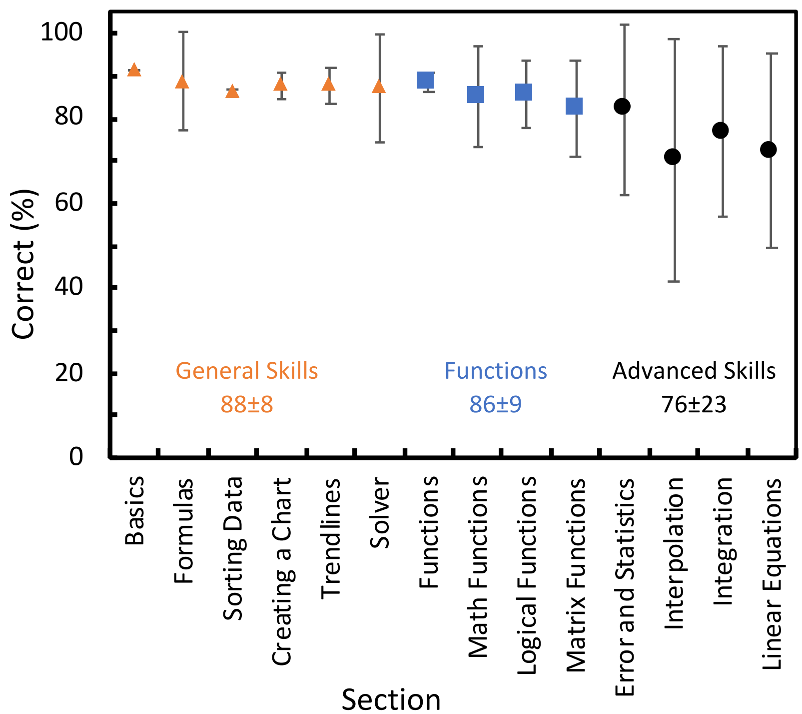


**Figure 3. Average grade (%) parsed across fourteen sections combining five cohorts. Orange triangles represent General Skills, blue squares represent Functions, and black circles represent Advanced Skills. Shapes represent mean of all questions in the section, and error bars represent one standard deviation. Means and standard deviations (%) aggregated by category are given below the category textboxes.**

Examining fraction correct at the individual section level elucidates information related to specific spreadsheet concepts. Mean fraction correct for the six sections categorized General Skills was between 86 and 91% with standard deviations from less than 1% to 12%. The Sorting Data section resulted in the lowest overall mean at 86%. Four of the six sections within the General Skills category, had less than 1% standard deviation, while the Formulas and Solver sections had standard deviations at 11 and 12%, respectively. The Formulas section contained two challenge activities. The first activity covered formulas, lists, and ranges, which had a higher fraction correct than the second, 7-level challenge activity involving simultaneous entry of formulas and calculations using absolute references, i.e., the $, in different contexts. The challenge activity in the Solver section contained five levels primarily examining student's skills in fitting a model using squared residuals. Using real time data from challenge activities, faculty can address spreadsheet skills with low fraction correct as part of just-in-time teaching strategies during the next class [48].

Fraction correct for the Functions category was between 82 and 89% with standard deviations ranging between 2 and 12%. The Advanced Skills category had the lowest fraction correct with a range between 70 and 82% and large standard deviations ranging from 20 to 28%. The lower mean correct and larger standard deviations for the Advanced Skills sections compared to the other two categories may be attributed to first time exposure to the concepts in these sections. For example, many students in the course are taking Calculus I for the first time, so integration is likely a relatively new topic, and performing numerical integration in a spreadsheet is a new skill requiring transfer of knowledge from a math course to an engineering course.

Based solely on fraction correct, additional statistical analysis generally confirms the division of sections into three categories. Performing ANOVA to compare sections within a single category shows statistical similarity for both General Skills ($F(5, 2496) = 1.2$, $p = 0.29$) and Functions ($F(3, 1566) = 2.2$, $p = 0.09$). Thus, the challenge activities within these categories can be inferred to have the same average difficulty. On the contrary, the four sections deemed Advanced Skills showed varying fraction correct ($F(3, 1566) = 8.1$, $p < 0.0001$), which likely captured the diversity of these concepts and calculations. Finally, comparing across all sections found variation in fraction correct ($F(13, 5614) = 14$, $p < 0.0001$).

Over 62,000 attempts across 472 questions were recorded for four cohorts (**Figure 4**). Attempts data from the 2020 cohort were not collected due to a flaw in attempts counting algorithm within the interactive textbook platform. Median attempts ranged from 1.1 to 2.2 attempts before correct, which seems to be a reasonable number. A baseball analogy could be used here, and at least half of the students are correctly completing the auto-graded spreadsheet problems before three strikes are reached. The section covering interpolation had the highest attempts before correct, which included a $1^{st}$ quartile of 1.8, median of 2.2, and $3^{rd}$ quartile of 3.0 attempts. This measurable struggle to complete auto-graded problems related to interpolation likely drives the high animation view rates discussed above, which has not been seen in previous work. Thus, the utility of animations to help solving auto-graded problems is identified for the first time.

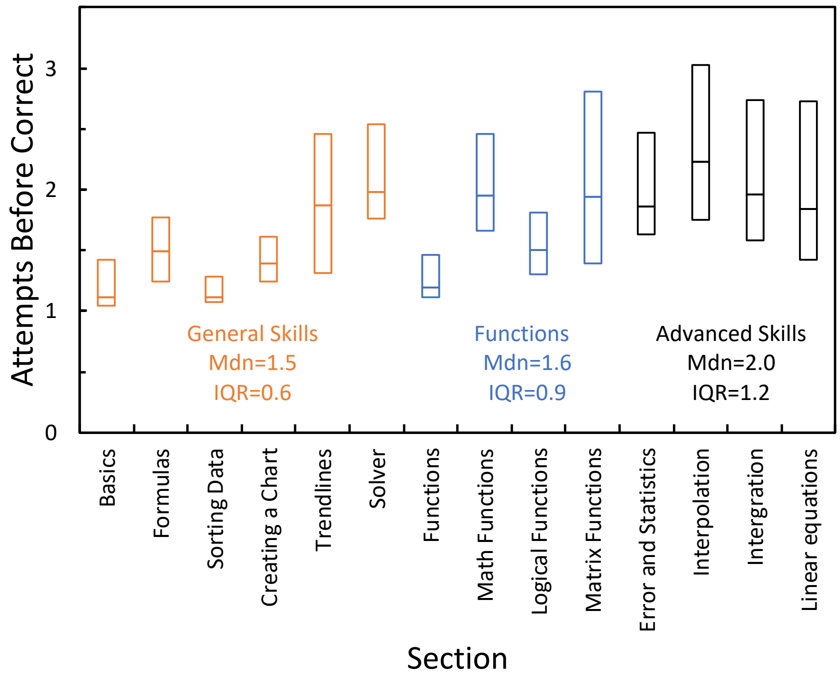


**Figure 4. Attempts before correct on auto-graded spreadsheet problems by section of the interactive textbook. Color distinguishes six General skills sections, four Functions sections, and four Advanced Skills sections. Median and interquartile range are included for all sections. Aggregated over four cohorts (2018, 2019, 2021 and 2022) and 309 students.**

Additional statistical analysis shows variations in attempts before correct both within each of the three categories and across all sections ($F(13, 458) = 7$, $p < 0.0001$). Performing ANOVA on attempts before correct within each category found: General Skills ($F(5, 142) = 12$, $p < 0.0001$), Functions ($F(3, 134) = 7.0$, $p = 0.0002$), and Advanced Skills ($F(3, 182) = 0.7$, $p = 0.56$). While the four sections deemed Advanced Skills showed measurable variation in fraction correct (discussed earlier) but had similar attempts before correct. These data may imply that some students will stop attempting problems after about 3 attempts; 1$^{st}$ quartile attempts generally showed that only about 25% of students answer correctly after more than 3 attempts.

One final metric is worth noting also. Extra attempts quantified attempts after a student has correctly answered a problem once. For the four cohorts examined here, over 2,000 extra attempts were completed. Therefore, students quantitatively re-used the auto-graded problems for practice of spreadsheet skills without any grade incentive. By documenting these problem-solving activities outside of those required for a grade aligns well with self-regulation theory [49-51] as well as lifelong learning goals of ABET and many engineering programs.

## Conclusion

First-year engineering students' spreadsheet skills were analyzed using reading participation and both correct and attempts on auto-graded problems within an interactive textbook. In general, reading participation and fraction correct on auto-graded problems were statistically similar across all cohorts. The median reading participation was 97% or higher, which is significantly larger than other higher education textbook reading rates. The 120+ auto-graded problems included randomized numbers and cell locations, immediate feedback, scaffolding, and unlimited attempts, which aligned well with the tenets of deliberate practice. Overall, average correct varied between 70 and 91% across the 14 sections. The median number of attempts before correct varied between 1.1 and 2.2, which was considered reasonable. Lower fractions correct correlated with higher attempts before correct for most sections.

Overall, the interactive homework and auto-graded problems provide an instructor with tools to document students introduction to and application of spreadsheet skills without a large grading burden. For example, specific skills that students struggle with, such as interpolation, can be measured in real time, which allows for instructor interventions in the vein of just-in-time teaching.

Several limitations of this learning analytics study merit discussion. First, no control group of learners was used, and no comparable cohorts performing spreadsheet skills were found in the literature. Also, no independent or validated spreadsheet skills assessment was used; developing and applying a pre/post assessment could better quantify the transfer of spreadsheet skills to new situations. Having about a week to work on each set of problems, students could potentially work together on the auto-graded problems, which is partially mitigated by the randomized numbers and cell locations.

Exploring evidence-based practices, including scaffolding and self-regulation, is possible using interactive textbooks, and the authors hope to explore mastery learning and developing validated assessment tools for spreadsheets in the coming years.

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