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Teaching Fundamental Skills in Microsoft Excel to First-Year Students in Quantitative Analysis

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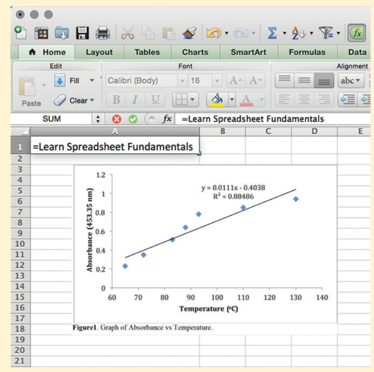
Ⓢ *Supporting Information*

ABSTRACT: Despite their technological savvy, most students entering university lack the necessary computer skills to succeed in a quantitative analysis course, in which they are often expected to input, analyze, and plot results of experiments without any previous formal education in Microsoft Excel or similar programs. This lack of formal education results in increased anxiety, students spending large amounts of time using the process of "trial and error" to complete the assignments, and detracts from the students' learning of the chemistry. Microsoft Excel tutorials that were previously introduced have either been not specific to chemistry, require multiple assignments throughout the semester to acquire the necessary skills, or are designed for deprecated versions of the software. In this work, we present an argument for implementing a chemistry-specific, version-agnostic spreadsheet interactive laboratory exercise that uses basic, general chemistry concepts to have students explore and learn the computer skills that are necessary to succeed in a quantitative analysis course. Student feedback data indicate that students felt that the interactive spreadsheet lab allowed them to develop skills that they identified as necessary for success in the course as well as for their future careers.



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INTRODUCTION

A crucial responsibility of a university in the 21st century is to ensure that students graduate with the necessary skills to thrive in a changing, technological environment. A study of employers recruiting graduates at Cornell University emphasized the importance of specific computer skills when entering the work force. Employers regarded general numerical data skills, the ability to perform detailed analysis, and specifically spreadsheet skills as important.[1] Furthermore, these same computer skills are also necessary to succeed in chemistry courses with a strong focus on quantitative analysis. Surprisingly, while most undergraduates matriculate already skilled in the use of word-processing software, most of them lack any prior experience with spreadsheets.[2] To be successful in their first-year chemistry labs, students are required to become proficient in a large amount of basic chemical principles, new technical lab techniques, and research-based writing skills. In addition to all of those, they must also quickly acquire the necessary computer skills to organize, analyze, and present their findings in a clear and concise manner. The combination of all these factors can often cause anxiety and distract students from their learning goals. While it might seem that an ideal solution to this problem would be to require all chemistry students to take a separate course in statistics and in computer programming, the idea of delaying students from beginning their chemistry coursework, and adding yet another course requirement, is neither feasible nor desirable.

Microsoft Excel is an ideal program for teaching data management skills, graphic presentation of data, and statistical analysis. In comparison to specialized statistics packages such as SAS or SPSS, Excel is widely available in industry and is offered at a low cost for undergraduates.[1] Excel can be used to organize data in a clear and understandable way, perform complex calculations without round-off error, and give students the flexibility to correct calculation errors by adjusting a few linked cells without the need to mechanically recalculate numerical values. Additionally, the built-in formula builder makes basic functions and statistics easily accessible, even for the novice user. Finally, the easy-to-follow graphical interface allows students to easily present their data in a clear manner, without having to learn the programming codes often necessary for some of the more specialized statistics packages.[3]

Although there exist published manuals for teaching the basics of spreadsheets and statistics using Microsoft Excel, few are specific to chemistry.[4,5] Additionally, those materials that are chemistry-specific are similarly undesirable, as they are written for specific versions of Excel, which can sometimes change substantially from version to version. Furthermore, many of these tutorials are organized in a way that requires multiple assignments throughout a semester to become proficient in the necessary skills.[6,7] Sink and co-workers (1992) describe the process of teaching students to use spreadsheets in a First-Year Chemistry Laboratory; however,

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the method was described for students using obsolete hardware and software.[8] This *Journal* has extensively discussed the use of spreadsheet templates for chemistry labs including kinetics,[9,10] equilibrium concentrations,[11] and potentiometric titrations.[12] Unfortunately, the approach of using premade templates can often lead to students short-circuiting the learning process; they do not learn how to produce their own spreadsheets, which means that they are less likely to continue using these skills in future courses.

Herein, we propose a tutorial in which students learn to use spreadsheets to organize data, and solve chemistry-relevant problems, in a software-agnostic and version-agnostic manner. Though students are encouraged to use Excel, the tutorial guides the students through discovering the basic abilities of a spreadsheet, exploring the different functions that are available in the package, and using their spreadsheet to solve problems. The tutorial is given during the first lab period, and students then build on this foundation throughout the rest of the semester using inquiry-based learning. Moreover, learning these skills as first-year students allows the students to continue to use, and build on, these skills in future courses, and to apply them in their professional careers.

Prior to using this tutorial, students in prior years that enrolled in our first-year quantitative analysis lab courses were required to learn spreadsheet skills without any official instruction in order to complete their laboratory assignments. For example, students would have to learn for themselves how to tabulate titration data and plot spectra. While some would be motivated to attend office hours for informal instruction, many students would consult with previous students or use the method of "trial and error." This model of learning, through "trial and error," is common in other universities; students at Cornell University questioned about their computer literacy revealed that they feel "moderately confident with their spreadsheet skills" and "there was unanimous agreement that professors assume students have specific software skills without providing any support or training, which was a source of considerable frustration and stress."[13]

DESIGN OF SPREADSHEET TUTORIAL

The Excel laboratory exercise was designed with several goals in mind: to be approachable for novice chemistry students, to be software-version agnostic, to give students an appreciation for the types of analyses that they can do with Excel, and to support students irrespective of their level of computer proficiency.

New versions of software packages like Microsoft Excel are released at somewhat regular intervals and are often accompanied by significant changes. Furthermore, the versions for PC and MAC operating systems are also quite different. While most of the functionality is unchanged from version to version, the specific keystrokes and screens will often vary substantially. A common criticism of software tutorials is that they are too version-specific, requiring that the tutorial be rewritten for each new version of the software. Additionally, tutorials that provide too much direction, requiring the user to only execute commands without reflection, are less likely to be effective. Therefore, the tutorial that is presented here does not contain specific keystroke commands, nor step-by-step directions to complete tasks. Rather, students are informed about basic abilities and functionality of the software, and are then guided in determining and executing the appropriate commands.

Students enter the class with varying backgrounds in chemistry and computer programming. Consequently, the tutorial is designed in a manner where students work through basic chemistry problems using the model of "show, try, and think". This model assumes that the students do not have any previous experience working with spreadsheets, and allows students to gain confidence with the software by solving problems that are approachable. Each *show, try, think* task is structured so that the students first work through a problem step-by-step along with the text in the tutorial, then try to solve a problem on their own where the answer is provided, and subsequently tackle an assignment where the answer is not revealed.

It is possible to teach the skills necessary for using spreadsheets in a theoretical framework or through practical hands-on learning. The chemistry lab class is an optimal environment for students to learn to use spreadsheets through active learning; they spend hours gathering data from their experiments and then use spreadsheets to organize, analyze, and present their data. The other possibility would have been to teach students how to use spreadsheets through theoretical problems designed by the professor, which might make it more difficult for students to translate the skills they learned in other contexts.

METHODS

Context and Target Group

Students were surveyed to determine the effectiveness of using a laboratory tutorial for teaching fundamental skills in spreadsheets to students in introductory quantitative analysis. The surveys were administered to students enrolled in the 'Intensive General and Quantitative Analytical Chemistry' and 'General and Quantitative Analytical Chemistry' courses in Fall 2013 at Boston University. Of the 170 students completing the courses, a group of 156 students responded to the "pre-semester" survey and 146 students completed the "post-semester" survey through the blackboard interface. All of the students completed the spreadsheet tutorial as their first chemistry lab of the year. Participation in the pre-semester and post-semester surveys was voluntary and all student responses were anonymous. Administration of the survey was approved by the Boston University Institutional Review Board.

Survey

The established Likert-scale attitude survey was administered to all participating students at the beginning of the semester (pre-semester) before the spreadsheet tutorial was distributed.[14] The students were then asked to complete a similar survey at the end of the semester (post-semester). The surveys asked students about their attitudes regarding spreadsheet organization, data analysis, data presentation, and the chemistry class in general. Some questions, such as the students' desires to learn certain aspects of using spreadsheets, were only asked on either the pre-semester or post-semester survey, depending on their relevance. A Student's t test with an α value of 0.05 was used to determine significance between the pre-semester and post-semester surveys.

Description of the Tutorial

The tutorial begins with a limiting reagent problem and a simple dilution problem. Using these two problems, students are taught the fundamentals of spreadsheets and how to use spreadsheets in a step-by-step process to solve chemistry

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Worked Example #1: If you mix 5.000 grams of $Fe_2O_3(s)$ with an excess of $CO(g)$, a) how many grams and molecules of $Fe(s)$ will form, and b) how many grams and molecules of $CO_2(g)$ will form?

$$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$$

Start by generating the following table in your spreadsheet:

	A	B	C	D	E
1		stoichiometry	grams	moles	molecules
2	Fe_2O_3(s)	1	5.000		
3	Fe(s)	2			
4	CO_2(g)	3			
5	CO(g)	3	excess	excess	excess

Figure 1.1: Worked Example #1

Solve for the number of moles of $Fe_2O_3(s)$ (you should get 0.03131 moles of $Fe_2O_3(s)$ in cell **D2**).

Fill in the remainder of the table.

You may realize that there are an excessive number of decimal places in some of your values. Excel does not know how to account for significant figures by itself, nor do you need to worry about significant figures. Consider Excel to be an overgrown calculator; it isn't relevant how many figures Excel shows. Rather, it is the number that you report in your assignments that is important.

That said, you may want to change the number of decimal places that are being displayed (to make it easier to read or to see more detail). This is accomplished with the *format cells* feature. With this feature it is possible to convert the numbers within the cells to the correct number of significant figures, scientific notation, fractions, percentages, and many other formats that you may need.

Convert values in column D into scientific notation, and all values within the table to have three decimal places (cell **D4** should read 9.393×10^{-2})

Figure 1. Example of "Worked Example" from the Excel tutorial lab.

Problem #2: $NaOH(aq)$ is often used to titrate $HCl(aq)$.

$$HCl(aq) + OH^-(aq) \rightarrow Cl^-(aq) + H_2O(l)$$

A 0.500*M* NaOH solution is used to titrate several aliquots of 25.00 mL of an unknown concentration of HCl. Use the data in the table below and the skills in this tutorial to determine the average concentration of the hydrochloric acid solution and the standard deviation. Provide a handwritten sample calculation (for one trial) in the post-lab assignment.

Trial #	Volume NaOH (mL)
1	15.55
2	15.77
3	15.54
4	16.01
5	15.89
6	15.99
7	15.62
8	15.66
9	15.71
10	15.84

Figure 2. Example of a problem for students to solve independently using their spreadsheet skills.

problems. While students attempt to use spreadsheets using the worked examples, they are also encouraged to work with their lab instructors for additional guidance.

Figure 1 depicts the type of straightforward problem that students are guided toward completing (please refer to Supporting Information for further information on worked examples). Using familiar concepts such as limiting reagent problems, students review fundamental concepts that will be indispensable in their quantitative course, while beginning to understand the utility of using spreadsheets to work out problems.

While some students may have been exposed to spreadsheets in past coursework, this collection of problems gives all students the ability to explore the utility of spreadsheets in the context of a chemistry lab course. In total, students spend between 2 and 3 h to complete the tutorial based on the reports of teaching assistants.

The worked examples serve as a low-barrier introduction to the fundamental utilities of Excel and walk students through

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problem solving (Show). Once students complete the step-by-step worked examples, they are directed to solve three Problems to assess their proficiency in the desired skills (Figure 2 and Supporting Information). Working independently, but with the supervision of a guiding teaching assistant, students solve a basic dimensional analysis problem, analyze titration data, and then prepare a calibration curve (Try). Follow-up questions in lecture, and the remainder of the semester, have students build on these new skills (Think).

■ RESULTS AND DISCUSSION

The implementation of a chemistry-focused Excel tutorial exercise, geared toward teaching students how to use spreadsheets in a chemistry laboratory class, has been transformative in the undergraduate general and quantitative analytical chemistry courses at Boston University. Before implementing the tutorial, students who were not already proficient with spreadsheets were largely unsuccessful at learning and developing the skills that they needed. While they understood the value in learning the skills, many found that it was too time-consuming and detracted from their overall chemistry education.

Student Perception of the Tutorial Benefit

Data in Table 1 (Pre-semester Survey) indicate that an overwhelming percentage of students entered their first year as undergraduate students with the desire to learn to use spreadsheets. In their post-semester survey, the vast majority of students responded that they felt that the tutorial was successful in teaching them the desired skills. Many students in college take classes for the goal of achieving a high grade or to complete a requirement for a major. Many pre-medical students, for instance, will take introductory chemistry courses with the goal of achieving a high grade without a sincere interest in learning chemistry. The data indicate that students do have a sincere interest in learning to use spreadsheets because they realize that they are acquiring valuable skills that will help them in multiple college courses in addition to their professional careers (92 ± 4%). Additionally, many students enter introductory chemistry courses with the false belief that they are already sufficiently knowledgeable in chemistry, from high school chemistry courses, to receive a high grade.[15] However, the responses to the survey indicates that students recognized spreadsheet skills as a potential deficiency in their education before the semester had begun and were eager to close the gap in their knowledge.

Table 1. Comparative Results of Students' Responses about Learning Spreadsheet Skills

Statements for Student Response[a]	Agreement with the Statements, %: Pre-semester Survey (N = 156)	Post-semester Survey (N = 146)
Use a spreadsheet to organize data	86 ± 5	93 ± 4
Use a spreadsheet to perform analysis of lab data	92 ± 4	89 ± 5
Use a spreadsheet to create charts and graphs	81 ± 6	93 ± 4
I will need to know how to use spreadsheets for my professional career	92 ± 4	—

[a]For the pre-semester survey, the first three statements were introduced in the context of "I have a desire to learn to...". For the post-semester survey, the first three statements were introduced in the context of "The tutorial was successful in teaching me to...".

Changes in Student Perception of Proficiency with Spreadsheets

Students demonstrated varying levels of confidence in using various aspects of spreadsheets at the start of the semester. However, by the end of the semester, students indicated a substantial increased level of confidence in all categories listed (Table 2). Students felt least confident using Excel to perform analysis of raw data at the beginning of the semester (28 ± 7%), the most tedious and time-consuming of chemistry-related data tasks, but there was a substantial increase in confidence (229%, p < 0.0001) by the end of the semester. There was also a significant increase in the percentage of students who learned how to organize data (59%, p < 0.0001). Finally, while students felt the most confident in their abilities to use spreadsheets to create charts or graphs before starting the course, there was still a significant (31%, p < 0.0001) increase of confidence within this category. Overall, confidence in using spreadsheets rose from 55% to 96% in the two classes by the end of the semester.

Table 2. Comparative Results of Students' Perceptions of Increased Spreadsheet Skills

Statements for Student Response	Agreement with the Statements, %: Pre-semester Survey (N = 156)	Post-semester Survey (N = 146)	Relative Increase in Confidence
Confident using a spreadsheet to organize data	61 ± 7	97 ± 3	59
Confident using a spreadsheet to perform analysis of lab data	28 ± 7	92 ± 4	229
Confident using a spreadsheet to create charts and graphs	75 ± 7	98 ± 2	31
Overall confidence (average)[a]	55 ± 8	96 ± 3	75

[a]"Overall Confidence" was calculated by averaging responses to these statements: "Confidence using spreadsheets to organize data"; "Confidence using spreadsheets to perform analysis of lab data"; and "Confidence using spreadsheets to create charts and graphs".

Overall Effect of Tutorial on Coursework

It is always important to consider how adding new material, especially technological, will impact the anxiety level of students in a course. Although 68% of students were nervous about the lab class at the beginning of the semester, only 11 ± 5% of students report that the spreadsheet tutorial had specifically increased their initial anxiety about the chemistry lab (Table 3). Given the substantial increases in student confidence, however, we argue that this small increase in anxiety is acceptable given the outcomes. Indeed, one substantial benefit of assigning the tutorial as the first lab is that teaching students how to use

Table 3. Comparative Results of Students' Perceptions Concerning General Quantitative Analytical Chemistry

Spreadsheet Survey Statements for Student Response	Agreement with the Statements, % (N = 146)
The spreadsheet tutorial increased my anxiety	11 ± 5
Using Microsoft Excel has reduced my time analyzing data	76 ± 7

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spreadsheets within this situation reduced the time necessary for completing data analysis in future weeks from the typical 4 to 6 h (reports based on previous anecdotal evidence) to 3.1 ± 1.0 h (from the survey data).

Many students enter their first year in college stressed by the large amount of material that they are required to learn. More specifically, in Intensive General and Quantitative Analytical Chemistry and General and Quantitative Analytical Chemistry students are expected to learn a large amount of chemistry content, technical lab skills, writing skills to write proper lab reports, statistics necessary to present lab data, and the computer skills necessary to organize, analyze, and present this lab data. This tutorial was successful in relieving some of the stress for students associated with all the different components required to postprocess lab data and prepare to draft a lab report. The time students saved using the spreadsheet tutorial could then be allocated for other aspects of the chemistry course or other courses.

Among other places where spreadsheets can help students to save time, using Excel to perform statistical analyses of large data sets can be especially time-saving. According to Bell (2001), one weakness of teaching students statistics with Microsoft Excel is that students often plug numbers into the spreadsheet without fully understanding the resulting values.[1] However, the problem of having a lack of understanding for the meaning of the statistical analysis being performed does not apply to General Analytical Chemistry because the students are required to submit their handwritten results and analysis, including any statistical work for all lab exercises. Additionally, their submissions include the meaning and significance of the data analyses performed. The use of spreadsheets, in this case, is only meant for streamlining the analysis process and decreasing numerical round-off error.

It is clear that many students enter their first year of undergraduate education lacking in basic computer skills that are crucial for the classroom and in the workforce. It certainly could be argued that it might be beneficial to begin teaching many of these spreadsheet and presentation skills in high school, with the goal of developing basic computer literacy before they matriculate at an undergraduate institution. They can learn these skills in their math or science classes, and can then further develop and refine these skills throughout their undergraduate training so that they are fully prepared for graduate education or entrance into the workforce.

Finally, it is interesting to note that many Boston University chemistry majors have mentioned at their exit interviews that learning to use spreadsheets in general chemistry during their first year was highly beneficial for the subsequent three years of undergraduate education, including upper-division laboratory courses in instrumental analysis and physical chemistry.

A limitation of this study is that it was conducted in intensive first-year chemistry courses with a total class size of approximately 180 students, most of whom were majoring in chemistry or biochemistry. This tutorial has not been tested, however, in the nonmajors general chemistry class, which has a much larger and more heterogeneous student population. Furthermore, this tutorial was administered by one chemistry professor (B.A.), and further research should be done to determine whether this tutorial would be as successful when taught by other professors at other universities. While it would have been more conclusive to compare the experimental group (group using the tutorial) to a control group (group not receiving the tutorial), we felt that it would be unethical to create a control group by not providing a group of students with this valuable educational tool.

CONCLUSION

With the rapidly changing technological environment that we live in today, it is crucial for students completing undergraduate education to have computer skills, including the ability to use spreadsheets. The spreadsheet tutorial distributed to students in the General Analytical Chemistry courses increased their overall confidence in organizing, analyzing, and presenting lab data. The tutorial was also successful in decreasing some of the anxiety related to the class and saved students time when analyzing lab data. Rather than using theoretical or irrelevant problems, this tutorial uses chemistry-related problems and guides students through experience-based learning; consequently, this tutorial lab was successful in increasing student chemistry knowledge, while providing them with useful skills that can be applied in other contexts and disciplines as well. We feel that the results of this study support the implementation of a spreadsheet tutorial lab at the start of general and quantitative analytical lab courses. Deciding which spreadsheet or statistics program should be taught, however, surely depends on other factors such the size of the data sets that will be studied and the sophistication of the statistical tests that will be used.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00122.

Student lab handout and instructions (PDF)

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Notes

The authors declare no competing financial interest.

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