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Visualization of Kinetics: Stimulating Higher-Order Thinking via Visualization

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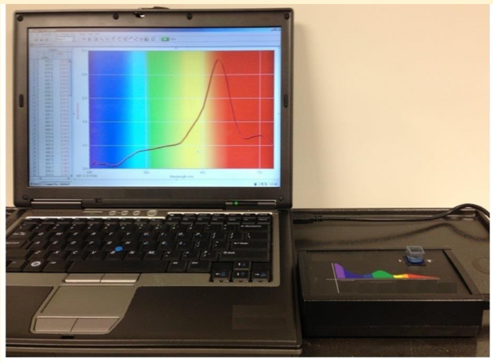
Supporting Information

ABSTRACT: When students are able to visualize data in real time they can think at higher levels of analysis and evaluation because the data arrive immediately. A kinetics laboratory was modified to include real-time visualization. On the basis of completion of laboratory questions, quiz, and an end-of-semester assessment, students demonstrated they could connect several disparate concepts related to kinetics.



KEYWORDS: *First-Year Undergraduate/General, Laboratory Instruction, Hands-On Learning/Manipulatives, Kinetics, Laboratory Computing/Interfacing, Laboratory Equipment/Apparatus, UV–Vis Spectroscopy*

INTRODUCTION

Kinetics is a common second-semester topic in general chemistry addressed in most textbooks.[1−5] Previous work has addressed kinetics experiments for college students,[6−10] perhaps because the topic is conceptually challenging. These experiments have focused on details of the kinetics experiments, yet little attention has been paid to the student learning experience via the postlab questions.

This lab uses the disappearance of blue food color in a sodium hypochlorite solution to introduce kinetic concepts (see the Supporting Information). The original protocol was revised to help students focus on the higher-order cognitive skills of application and analysis[11] where the students are asked questions that require them to

- *Analyze* their experimental data as they use various graphs to determine the order of reaction of blue food colored solution and a bleach solution
- *Calculate* and *compare* the wavelength values associated with the minimum and maximum absorbance values of a blue food colored solution
- *Explain* the difference between absorbance and transmittance in relation to the graphical observation of a peak of minimum and maximum absorbance
- *Evaluate* a graph of absorbance vs time (understanding there is a direct relationship between absorbance and concentration) to determine half-life

Similar laboratory experiments that involved the study of kinetics of bleach and food coloring have appeared elsewhere,[12−15] as well as other experiments addressing the kinetics of solutions of sodium hydroxide and phenolphthalein[16] or crystal violet,[17] though not with the possibility of real-time visualization with subsequent data analysis. Of the four laboratories that used bleach plus a food dye, three determined the pseudo[18] order of both the dye and bleach.[12,13,15] The lab using sodium hydroxide and phenolphthalein[16] determined the order of both reactants, whereas two laboratories only determined the order of the dye[14] or crystal violet.[17] In this respect, the kinetics lab addressed in this paper is similar to previous ones, though both the pseudo order[18] of the blue food colored solution and bleach are determined.

Previous laboratories appear to have not addressed the pedagogical concept of the simultaneous ability to immediately observe both the visual and graphical representation of the kinetics. In previous laboratories, various spectrophotometers were used;[12−17] however, it appears there was not an immediate observation graphically as the absorbance decreased over time. Instead students were required to record absorbance values from the spectrophotometer at specified intervals of time to be plotted later using a program such as Excel followed by graphical analysis.

In all of the laboratories students were told the maximum wavelength in nm that was to be used. When there is an immediate visual graphical display of the wavelength of maximum absorbance at which the data are to be recorded, such as in the lab addressed in this article, an opportunity is provided to question students about the complementary nature

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of the color absorbed and transmitted by the blue colored solution.

When students need to record their data, later enter the data into a program such as Excel, and then analyze the results, there is less time to devote to collaborative work. This modified protocol allows additional time to complete the lab and address the postlab questions. This lack of time was an issue in previous laboratories and the quick generation of graphs of the different variables allowed more time to work collaboratively on the postlab questions.

■ REVISED EXPERIMENTAL PROTOCOL

This modified kinetics experiment engages students at higher-order cognitive skills through the analysis of their graphical results. In addition, they must answer questions determining the order of a reactant both mathematically and graphically. Students also learned new laboratory skills that permitted them to maximize the graphical capabilities of the software and spectrophotometer used.

Though a visual color change was timed in previous kinetics laboratories, the time recorded was not always accurate; that is, student results were not consistent. With the laboratory equipment used in this lab, an immediate visual and graphical display of the time was produced.

Students have been introduced to the complementary nature of absorbance and transmittance in a first-semester lab, but their answers demonstrated a lack of comprehension as shown by a typical student response:

> *The minimum absorbance value is the shortest wavelength of light in the visible spectrum that can be transmitted or absorbed. Likewise, the maximum absorbance value is the longest wavelength of light in the visible spectrum that can be transmitted or absorbed.*

This states what students saw on a graph of absorbance versus wavelength but it does not provide an explanation of the complementary nature of absorbance and transmittance. Students were expected to further reflect on these concepts.

■ CONCLUSION

The most obvious impact of the lab was the immediate visualization of graphical display; rather than having to collect data and then later graph the data, learners could see the results as they appeared. The ability to follow the color change could then be correlated with the accumulating data being graphically displayed. Critics might argue that learning is compromised through such a technological intermediary, and while plotting information is certainly an important skill, interpretation of graphical analysis seems more important. The immediate visualization of both a color change and graph combine to help students learn more efficiently, perhaps leaving more time to verbally ask students questions about the results.

The goals of the modification were successful. For example, students' answers to questions relating to the complementary nature of absorbance and transmittance showed they had a better understanding, as demonstrated by a typical student answer:

> *Because the maximum transmittance is the color blue, the complementary color of that is orange which is the maximum absorbance and is at a maximum wavelength of 629.7 nm. Since blue is the maximum transmitted color, that means it is the area of minimum absorbance. The complementary absorbance is then at orange which is the maximum absorbance at 443.6 nm.*

On a lab quiz, 82% of the students correctly answered a question not asked previously, namely, to explain the relationship between time versus concentration if the reaction with respect to bleach was second order. On a final semester exam, 78% of the students correctly answered a question when they were asked to identify the order of a reaction based on the rate expression.

Experimentally the use of the software and spectrophotometer provided more consistent results and repeatability within a class. The class results were discussed at the completion of the lab and the students were required to calculate the mean and standard error of the class data. Because students have experience with these terms from several previous laboratories and have demonstrated they understand them based on several assessments, they were able to determine whether the data collected had meaning and discuss possible sources of error. The students' laboratory skills were enhanced as they generated graphs and obtained the linear regression using graphical analysis capabilities they had not used previously.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00215.

Student handout (PDF, DOCX)

Instructor notes (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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