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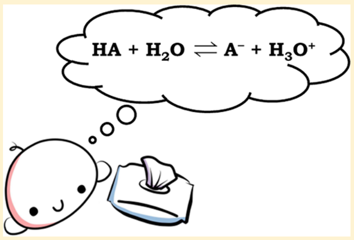
Buffers in Context: Baby Wipes As a Buffer System

Jon-Marc G. Rodriguez, Sarah Hensiek, Jeanne R. Meyer, Cynthia J. Harwood, and Marcy H. Towns*

Department of Chemistry, Purdue University, West Lafayette, Indiana 47907, United States

Supporting Information

ABSTRACT: An understanding of buffers is important in a variety of chemistry subdisciplines, with relevant applications to the life sciences and health profession-related fields. Here, we describe the development and implementation of a lab that involves creating a buffer solution using baby wipes and deionized water. The goal of this lab was to emphasize a conceptual understanding of buffers within a context that would be interesting and relevant for students in a nonmajors general chemistry course, a population composed primarily of health/human science and agricultural science majors. The prelaboratory assignment and postlaboratory discussion focus on modeling by making connections between laboratory observations and the particulate-level view of a buffer. Overall, the experiment seeks to prompt students to think beyond the macroscopic view that buffers resist changes in pH and guide students toward thinking mechanistically about *how* a buffer resists changes in pH, a process that depends largely on the buffer components and their respective amounts.



KEYWORDS: *High School/Introductory Chemistry, First-Year Undergraduate/General, Interdisciplinary/Multidisciplinary, Laboratory Instruction, Hands-On Learning/Manipulatives, Acids/Bases, Nonmajor Courses, pH*

Buffers play a critical role in biological systems by maintaining the physiological pH and preventing health complications that result from deviations in the target pH. Many commercial products utilize buffer systems to help maintain a particular pH. By controlling the pH using a buffer system, manufacturers can prevent microbial growth, increase shelf life, and fine-tune drug efficacy. Common examples of buffer solutions include contact lens solutions, skin care products, over-the-counter drugs, and baby wipes. Due to their wide application in a variety of contexts, buffers are often studied in multiple courses offered in chemistry and biology departments (e.g., general chemistry, analytical chemistry, biochemistry). Furthermore, in studies that have looked at chemistry topics and their relationship to health fields such as nursing, acid and base concepts such as pH/buffers were consistently ranked first in order of importance and were also consistently classified as important and relevant for nursing clinical practice.[1,2] However, previous literature suggests students have difficulty with concepts related to buffers, even after exposure to the content in multiple courses.[3] In the case of students intending to pursue a career in the health professions, this is particularly problematic because of the foundational role chemistry plays in fields related to the health sciences.[4]

The importance of buffers has also been recognized through work done by the ACS Exams Institute (ACS-EI). In the Undergraduate Chemistry Anchoring Concept Content Maps (ACCM) for General Chemistry released by the ACS-EI, it tersely defines buffers based on their ability to resist changes in pH (due to the presence of a conjugate acid−base pair), lists buffers as an application of equilibrium that is relevant in chemistry subdisciplines, and emphasizes the importance of understanding buffers conceptually and quantitatively,[5−7] but research demonstrates that understanding buffers is not trivial.[3] In a 2008 study by Orgill and Sutherland, the researchers determined students have difficulty with multiple concepts related to buffers: students tend to focus on a macroscopic view of buffers, attending to the fact that buffers resist changes in pH without understanding the mechanism involved; students are able to identify that buffers contain acids and bases, but they do not make the connection regarding the relationship between them (weak acid and *conjugate* base or weak base and *conjugate* acid); and students have difficulty determining what factors influence buffering capacity.[3] One of the suggestions by Orgill and Sutherland to help students better understand buffers and address the difficulties mentioned above is to help students consider the processes that are occurring within a buffer at the particulate level and guide them in making connections and modeling the buffer mechanism.[3]

One of the scientific practices outlined by the National Research Council (NRC) involves developing and using models, such as translating a process into a mathematical formalism, or thinking about a macroscopic system at the particulate level.[8] Modeling encompasses making connections between different domains and has been identified as a critical piece of conceptual understanding in chemistry, as described by the "chemistry triplet" that involves thinking about chemistry at the macroscopic, particulate, and mathematical levels.[9−11] However, the limits of the chemistry triplet have been noted, and revisions or alternative conceptualizations have been provided in the literature,[9,10,12,13] such as the

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Mahaffy tetrahedron, which augments the traditional triplet by adding a "human element" or rich context for the presentation of chemistry content.[13,14]

Laboratory experiments that place chemistry in a rich context for students have been previously published in this Journal,[15] as well as other laboratories that explore ideas related to buffers.[16] The experiment presented herein was designed with similar intentions, working toward placing chemistry in a context that is relevant and useful for students in the course, while simultaneously focusing on a conceptual understanding through the use and development of models. The experiment was designed for a nonmajors general chemistry course, with primarily health/human science and agricultural science majors, and it was inspired, in part, by an interesting study published in *Pediatric Dermatology* that studied the efficacy of baby wipes in reducing skin irritation through the use of a buffer system.[17]

PRELABORATORY DISCUSSION

The course associated with this laboratory experiment was designed so that the laboratory content is connected to and is discussed with the lecture content. By the time the students completed the buffer lab, they had already learned about equilibrium and (weak) acids/bases, performed two acid−base laboratories involving titrations, and received instruction about buffers in lecture.

The role of the prelaboratory questions were to prompt the students to start thinking about what they would be doing in lab, with an emphasis on getting students to model the buffer system by considering it at the particulate level. One of the prelab questions that highlights the buffer mechanism involves adding a strong base to a generic buffer system (see Box 1) and thinking about how this influences the components in the buffer. Student responses to this question should mention that the concentration of HA decreases (reacts with the base), the concentration of A^- increases (is produced), the amount of H_2O and H_3O^+ should remain roughly the same, and the pH should remain the same (or increase slightly). The additional prelab questions are included in the Supporting Information associated with this article.

Box 1

Equal amounts of a weak acid and its conjugate base are combined, resulting in the chemical expression below. Explain what happens to each of the terms in the equation after a strong base is added. How is the pH affected by the addition of a strong base?

$$HA + H_2O \rightleftharpoons A^- + H_3O^+$$

EXPERIMENTAL SECTION

For this experiment, the students worked in groups of two to prepare buffers and calculate the buffer capacity of each solution as described in the Supporting Information. The first portion of the experiment involved the students preparing an ammonia/ammonium ion buffer and two acetic acid/acetate ion buffers that contained differing amounts of sodium acetate. The rationale behind preparing two acetic acid/acetate ion buffers was to allow for direct comparison of the buffer capacity of these solutions and give the students a basis on which to make connections regarding how the relative amounts of weak acid and conjugate base influence the ability of the buffer to resist changes in pH. Due to time constraints, the students were not asked to prepare two different ammonia/ammonium ion buffers.

After preparing the three buffers described above, the students were directed to titrate two aliquots of each of these solutions to determine the buffer capacity, first titrating with a strong acid (hydrochloric acid) and then with a strong base (sodium hydroxide). By recording the amount of acid/base that was added to the buffer and the corresponding change in pH (the target was a change of one pH unit), students calculated the buffer capacity for each of the trials performed (acid or base titration). Using the same protocol, the buffer capacity of deionized water was also determined. In the last part of the experiment, the students prepared a solution from baby wipes and then determined the buffer capacity using the previously described protocol (for more information, see the provided Supporting Information). From a practical standpoint, the protocol for creating a baby-wipe buffer was simple and easy to implement, requiring little planning before the lab and reflecting a straightforward procedure for the students. The development of this protocol involved testing different wipe-to-water ratios. In order to have a large enough volume for the students to work with and have a solution that was concentrated enough to reliably behave as a buffered solution, we found it was effective for the students to use eight wipes in 90.0 mL of deionized water. The students simply had to place the baby wipes (straight from the package) into a 600 mL beaker, add the deionized water, and then twist and wring the baby wipes, collecting the solution in the same beaker. From this initial buffer solution the students pipetted aliquots and titrated to determine the buffer capacity. The laboratory experiment was designed to take roughly 2 h for the students to complete.

HAZARDS

Hazards associated with this laboratory experiment involve working with irritants and corrosive chemicals that may cause serious damage to skin and eyes. Proper personal protective equipment such as gloves and safety goggles are required. Chemicals used and their potential hazards include acetic acid (CAS No. 64-19-7), corrosive, causes serious eye damage/irritation; ammonium chloride (CAS No. 12125-02-9), harmful if swallowed, causes serious eye damage/irritation; sodium acetate (CAS No. 127-09-3), irritates skin, eyes, and respiratory system; aqueous ammonia (CAS No. 7664-41-7), harmful if inhaled, causes severe skin burns and eye damage; aqueous hydrochloric acid (CAS No. 7647-01-0), corrosive, causes serious eye damage/irritation; and sodium hydroxide (CAS No. 1310-73-2), corrosive, causes serious eye damage/irritation.

POSTLABORATORY DISCUSSION AND ASSESSMENT

During the laboratory experiment, the students recorded their data in their laboratory notebooks and reported their data on a laboratory report form that was provided for them (included in the Supporting Information). The report form contained all of the necessary data tables where the students could record their data and calculate values. After the students completed the laboratory experiment, they had additional discussion questions to address. The discussion questions prompted the students to analyze and interpret their data in the context of the chemical system they were studying. The experiment primarily required that students obtain data to determine the buffer capacity of the system, and so the postlaboratory questions supported students in making connections between their observations and developing a chemical understanding related to why the buffer capacity of an acetic acid/acetate ion solution changed when it was diluted, why deionized water did not resist pH changes, and why it may be useful to use one buffer system over another (e.g., acetic acid/acetate ion instead of ammonia/ammonium ion).

As a means to assess student understanding of buffers, the authors designed two multiple-choice questions that were administered as part of an exam in the course. According to the literature, students often have a fundamental misunderstanding about buffer strength/capacity, and they often have difficulty thinking about buffers on the particulate level, specifically, understanding the mechanism of how buffers resist changes in pH.[3] The questions were designed to address student alternative conceptions and focus on a conceptual understanding of buffers. The multiple-choice questions along with their responses and distractors (see Box 2) were designed by taking into account considerations of reliability and validity suggested by the literature (e.g., avoiding negative phrasing and absolute terms, items should only have one correct answer and should be answerable without looking at responses, etc.).[18] The first question in Box 2 was designed to test student understanding of buffer capacity and the factors that influence a buffer's ability to resist changes in pH, and the second question was designed to assess student understanding of the mechanism involved when a buffer resists changes in pH.

Box 2

1. **Buffer Capacity**
   A buffer has a ratio of $[A^-]/[HA] = 1/3$. How could the buffer capacity be increased?
   - **(a) Add more A^- to the buffer system.**
   - (b) Add more HA to the buffer system.
   - (c) Prepare a new buffer using a stronger acid that has a larger K_a.
   - (d) Prepare a new buffer using a stronger base that has a larger K_b.
2. **Buffer Mechanism**
   An ammonia/ammonium chloride buffer is set up and has the equilibrium below. When a small amount of strong acid is added to the buffer what happens to the concentrations of NH_4^+ and NH_3?

   $$NH_4^+\,(aq) + H_2O\,(l) \rightleftarrows NH_3\,(aq) + H_3O^+\,(aq)$$

   - (a) They remain unchanged.
   - **(b) $[NH_4^+]$ increases and $[NH_3]$ decreases.**
   - (c) $[NH_4^+]$ decreases and $[NH_3]$ increases.
   - (d) $[NH_4^+]$ and $[NH_3]$ both decrease.
   - (e) $[NH_4^+]$ and $[NH_3]$ both increase.

The laboratory was piloted during the summer session in 2017 with 15 students, which allowed us to test the laboratory and associated assessment questions. The laboratory experiment and the assessment that contained the questions in Box 2 were subsequently implemented in spring of 2018 with 826 students. The distribution of student responses for the two buffer questions is provided in Figure 1 below.

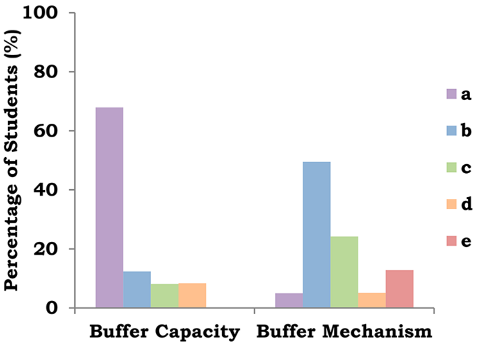

Figure 1. Student responses to the two multiple-choice assessment questions. The total number of students enrolled in the course was $n = 826$. For the buffer capacity question, the correct response is a, and the correct response for the buffer mechanism question is b.

In addition to the multiple-choice questions in Box 2 and Figure 1, the students in the spring also completed the free response question in Box 3 during their exam. This item assessed the extent to which students could carry out calculations and analyze data from the buffer capacity lab. In terms of NGSS science practices, this question assessed the students' ability to use mathematics, analyze and interpret data, and construct an explanation.[8] Although students likely had a model of a buffer that they used to answer the question, the model was implicitly used in constructing responses rather than explicitly assessed. The construction of this assessment item was guided by principles outlined in Underwood et al.'s recent article describing how to implement the three-dimensional learning assessment protocol (3D-LAP).[19,20]

Box 3

Buffer I: 10.0 mL of 0.50 M acetic acid 0.41-0.42 g sodium acetate 90.0 mL of deionized water	***Buffer II:*** 10.0 mL of 0.50 M acetic acid 0.11-0.12 g sodium acetate 90.0 mL of deionized water

Comparison of buffer capacity and deionized water.

Buffer	**Total volume of 0.10 M HCl added (mL)**	**Moles HCl added (mole)**	**|ΔpH| (change in pH)**	**Volume of buffer tested (L)**	**Buffer capacity (mole/L)**
acetic acid/acetate buffer I	16.90	X	1.02	0.0400	Y
acetic acid/acetate buffer II	5.31	5.31×10^{-4}	1.05	0.0400	1.26×10^{-2}
deionized water	0.10	1.0×10^{-5}	3.78	0.0400	6.6×10^{-5}

Given the data above:
(a) Determine the number of moles of HCl added to *Buffer I* (it's the box that has the X in it). Show your work.
(b) Determine the buffer capacity of *Buffer I*, it's the number that should go in the Y box and the formula is on the useful information sheet.
(c) Compare the buffering capacities of the two buffers to deionized water.
(d) How could you increase the buffering capacity of *Buffer II*? Explain your strategy.

Out of 803 students who took the exam, 31% completed all parts correctly or had only a small error such as leaving out the units in part a. Approximately one-third of the students struggled to correctly analyze and interpret the data and construct an explanation that earned half-credit or less. The grading and analysis of students' responses supported the generation of examination questions that required students to make their reasoning explicit through the construction of arguments based on evidence and explanations, which are two of the NGSS science practices.[8] As instructors, we learned more about the impact of the laboratory on student learning through this free response question in comparison to a multiple choice question regarding the definition of a buffer or buffer capacity. It further inspired us to revise our curriculum in the coming academic year to include instruction on constructing arguments and explanations in an effort to improve student performance in this regard.

It is worth stating that our discussion of buffer systems and our assessment of student understanding have been primarily qualitative in nature. Often when discussing buffers, students are expected to make use of the Henderson–Hasselbalch equation, as was the case for the previously published laboratory experiment in this Journal, which involved using student data to derive the relationship expressed in the Henderson–Hasselbalch equation.[16] In contrast, this laboratory experiment focuses on reasoning conceptually about the components of a buffer system, which provides insight into the mechanism involved in resisting changes in pH. Here, we place more emphasis on the chemical system, rather than the mathematical rendering of the Henderson–Hasselbalch equation, in order to help students understand more about the chemical phenomena; this was influenced in part by previous work that indicates students have difficulty reasoning conceptually.[21−31] Indeed, in the context of other general chemistry topics, students have indicated a preference for reasoning algorithmically.[21] Thus, our instruction and assessment redirects students' attention to a conceptual understanding of the underlying chemistry.

■ CONCLUSION

In the National Research Council's *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, science is presented as an integration of knowledge and practices that afford scientists the tools needed to solve problems and advance our understanding of the world.[8] With the adoption of the Next Generation Science Standards (NGSS), there is a movement toward an emphasis on engagement in science practices,[8] and although these standards were designed for the K−12 setting, it is important that undergraduate education, curriculum development, and assessment are informed by these changes.[32,33] In the case of chemistry laboratory courses, there is an inherent focus on skills and their integration with knowledge, making them particularly well suited for students to learn while engaging in science practices (e.g., modeling).

Here, we described the development of a laboratory exercise that sought to improve student understanding of buffer capacity and the buffer mechanism, with an emphasis on analyzing and interpreting data, constructing explanations, and modeling a buffer system at the particulate level. The laboratory experiment was placed in a context that may be of interest to our students in a nonmajors course who are primarily focused on careers in the health profession and agricultural sciences.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.8b00378.

> Possible prelaboratory questions, the laboratory protocol for students, a student report form, teacher's notes, and possible multiple choice and free response questions that could be posed on a quiz or examination (PDF)
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■ AUTHOR INFORMATION

Corresponding Author

*E-mail: mtowns@purdue.edu.

ORCID

Jon-Marc G. Rodriguez: 0000-0001-6949-6823
Marcy H. Towns: 0000-0002-8422-4874

Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) Walhout, J. S.; Heinschel, J. Views of Nursing Professionals on Chemistry Course Content for Nursing Education. *J. Chem. Educ.* **1992**, *69* (6), 483−487.

(2) Brown, C. E.; Henry, M. L. M.; Barbera, J.; Hyslop, R. M. A Bridge between Two Cultures: Uncovering the Chemistry Concepts Relevant to the Nursing Clinical Practice. *J. Chem. Educ.* **2012**, *89*, 1114−1121.

(3) Orgill, M.; Sutherland, A. Undergraduate Chemistry Students' Perceptions of and Misconceptions about Buffers and Buffer Problems. *Chem. Educ. Res. Pract.* **2008**, *9*, 131−143.

(4) Scalise, K.; Claesgens, J.; Wilson, M.; Stacy, A. Contrasting the Expectations for Student Understanding of Chemistry with Levels Achieved: A Brief Case-Study of Student Nurses. *Chem. Educ. Res. Pract.* **2006**, *7* (3), 170−184.

(5) Holme, T.; Luxford, C.; Murphy, K. Updating the General Chemistry Anchoring Concepts Content Map. *J. Chem. Educ.* **2015**, *92*, 1115−1116.

(6) Murphy, K.; Holme, T.; Zenisky, A.; Caruthers, H.; Knaus, K. Building the ACS Exams Anchoring Concept Content Map for Undergraduate Chemistry. *J. Chem. Educ.* **2012**, *89* (6), 715−720.

(7) Holme, T.; Murphy, K. The ACS Exams Institute Undergraduate Chemistry Anchoring Concepts Content Map I: General Chemistry. *J. Chem. Educ.* **2012**, *89* (6), 721−723.

(8) National Reseach Council. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas: Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education*; The National Academies Press: Washington, DC, 2012.

(9) Taber, K. S. Revisiting the Chemistry Triplet: Drawing upon the Nature of Chemical Knowledge and the Psychology of Learning to Inform Chemistry Education. *Chem. Educ. Res. Pract.* **2013**, *14*, 156−168.

(10) Talanquer, V. Macro, Submicro, and Symbolic: The Many Faces of the Chemistry " Triplet. *Int. J. Sci. Educ.* **2011**, *33* (2), 179−195.

(11) Holme, T. A.; Luxford, C. J.; Brandriet, A. Defining Conceptual Understanding in General Chemistry. *J. Chem. Educ.* **2015**, *92*, 1477−1483.

(12) Sjostrom, J.; Talanquer, V. Humanizing Chemistry Education: From Simple Contextualization to Multifaceted Problematization. *J. Chem. Educ.* **2014**, *91*, 1125−1131.

(13) Mahaffy, P. The Future Shape of Chemistry Education. *Chem. Educ. Res. Pract.* **2004**, *5* (3), 229−245.

(14) Mahaffy, P. Moving Chemistry Education into 3D: A Tetrahedral Metaphor for Understanding Chemistry. *J. Chem. Educ.* **2006**, *83* (1), 49−55.

(15) Domingo, J. P.; Abualia, M.; Barragan, D.; Schroeder, L.; Wink, D. J.; King, M.; Clark, G. A. Dialysis, Albumin Binding, and

Competitive Binding: A Laboratory Lesson Relating Three Chemical Concepts to Healthcare. *J. Chem. Educ.* **2017**, *94*, 1102.

(16) Kulevich, S. E.; Herrick, R. S.; Mills, K. V. A Discovery Chemistry Experiment on Buffers. *J. Chem. Educ.* **2014**, *91*, 1207−1211.

(17) Adam, R.; Schnetz, B.; Mathey, P.; Pericoi, M.; de Prost, Y. Clinical Demonstration of Skin Mildness and Suitability for Sensitive Infant Skin of a New Baby Wipe. *Pediatr. Dermatol.* **2009**, *26* (5), 506−513.

(18) Towns, M. H. Guide To Developing High-Quality, Reliable, and Valid Multiple- Choice Assessments. *J. Chem. Educ.* **2014**, *91*, 1426−1431.

(19) Laverty, J. T.; Underwood, S. M.; Matz, R. L.; Posey, L. A.; Jardeleza, E.; Cooper, M. M.; et al. Characterizing College Science Assessments: The Three-Dimensional Learning Assessment Protocol. *PLoS One* **2016**, *11* (9), e0162333.

(20) Underwood, S.; Posey, L.; Herrington, D.; Carmel, J.; Cooper, M. Adapting Assessment Tasks To Support Three-Dimensional Learning. *J. Chem. Educ.* **2018**, *95*, 207−217.

(21) Bain, K.; Rodriguez, J. G.; Moon, A.; Towns, M. H. The characterization of cognitive processes involved in chemical kinetics using a blended processing framework. *Chem. Educ. Res. Pract.* **2018**, *19*, 617−628.

(22) Cracolice, M. S.; Deming, J. C.; Ehlert, B. Concept learning versus problem solving: A cognitive difference. *J. Chem. Educ.* **2008**, *85* (6), 873−878.

(23) Nakhleh, M. B. Are Our Students Conceptual Thinkers or Algorithmic Problem Solvers?: Identifying Conceptual Students in General Chemistry. *J. Chem. Educ.* **1993**, *70* (1), 52−55.

(24) Nakhleh, M. B.; Lowrey, K. A.; Mitchell, R. C. Narrowing the Gap between Concepts and Algorithms in Freshmen Chemistry. *J. Chem. Educ.* **1996**, *73* (8), 758−762.

(25) Nakhleh, M. B.; Mitchell, R. C. Concept Learning versus Problem Solving: There is a Difference. *J. Chem. Educ.* **1993**, *70* (3), 190−192.

(26) Nurrenbern, S. C.; Pickering, M. Concept Learning versus Problem Solving: Is There a Difference? *J. Chem. Educ.* **1987**, *64* (6), 508−510.

(27) Pickering, M. Further studies on concept learning versus problem solving. *J. Chem. Educ.* **1990**, *67* (3), 254−255.

(28) Sanger, M. J.; Vaughn, C. K.; Binkley, D. A. Concept learning versus problem solving: Evaluating a threat to the validity of a particulate gas law question. *J. Chem. Educ.* **2013**, *90*, 700−709.

(29) Sawrey, B. A. Concept learning versus problem solving: Revisited. *J. Chem. Educ.* **1990**, *67* (3), 253−254.

(30) Stamovlasis, D.; Tsaparlis, G.; Kamilatos, C.; Papaoikonomou, D.; Zarotiadou, E. Conceptual understanding versus algorithmic problem solving: Further evidence from a national chemistry examination. *Chem. Educ. Res. Pract.* **2005**, *6* (2), 104−118.

(31) Zoller, U.; Pushkin, D. Matching Higher-Order Cognitive Skills (HOCS) promotion goals with problem-based laboratory practice in a freshman organic chemistry course. *Chem. Educ. Res. Pract.* **2007**, *8* (2), 153−171.

(32) Cooper, M. M. Chemistry and the Next Generation Science Standards. *J. Chem. Educ.* **2013**, *90*, 679−680.

(33) Reed, J. J.; Brandriet, A. R.; Holme, T. A. Analyzing the Role of Science Practices in ACS Exam Items. *J. Chem. Educ.* **2017**, *94*, 3−10.

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