JOURNAL OF CHEMICAL EDUCATION

Article

pubs.acs.org/jchemeduc

LabLessons: Effects of Electronic Prelabs on Student Engagement and Performance

Patrick Gryczka,[†] Edward Klementowicz,[‡] Chappel Sharrock,[§] MacRae Maxfield,[∥] and Jin Kim Montclare*,[‡,§]

[†]Department of Computer Science and Engineering, New York University Tandon School of Engineering, 6 MetroTech Center, Brooklyn, New York 11201, United States

[‡]Department of Chemical and Biomolecular Engineering, New York University Tandon School of Engineering, 6 MetroTech Center, Brooklyn, New York 11201, United States

[§]Department of Chemistry, New York University College of Arts and Science, 100 Washington Square East, New York, New York 10003, United States

[∥]Department of Chemistry, Brooklyn Technical High School, 29 Fort Greene Place, Brooklyn, New York 11217, United States

Supporting Information

ABSTRACT: Lab instructors, for both high school and undergraduate college level courses, face issues of constricted time within the lab period and limited student engagement with prelab materials. To address these issues, an online prelab delivery system named LabLessons is developed and tested out in a high school chemistry classroom. The system supplements the laboratory experience by providing visualizations and simulations of concepts to prepare students for the practical experiments. The system requires students to answer prelab questions online, which provides immediate feedback and cuts down on last minute copying of answers that instructors anecdotally reported with paper laboratories. Empirical results demonstrate the effectiveness and improved outcomes for students who have used LabLessons. In addition, the ease of use of the system and better preparedness for the lab is noted by the instructor.

KEYWORDS: *General Public, High School/Introductory Chemistry, Laboratory Instruction, Internet/Web-Based Learning, Multimedia-Based Learning, Testing/Assessment, Reactions*

■ DESIGN RATIONALE

In learning chemistry, as with all sciences, hands-on laboratory experience undoubtedly provides students an optimal experience. Though lab experience dates back to the 1800s, the effectiveness of such was described later by Tobin[1] who proposed that, "research [suggests] that meaningful learning is possible in laboratory activities if all students are provided with opportunities to manipulate equipment and materials while working cooperatively with peers." Since then, the role of laboratories in all levels of scientific education has grown to be a fundamental one. Though, historically, hand-writing has served as an indication of educated individuals,[2] with the boom of technology this practice has "outlived [its] usefulness".[3] There is now an emphasis placed on typing and an overall proficiency with computers. Specifically, technology implementation in high school classrooms has proven beneficial through the addition of touch-screen apps.[4] Technology implementation has "improved [students'] engagement in science, class participation, and understanding of the topics.[5] In such a technology-driven age, online modules can lure students when compared to conventional paper prelabs. Though there are technologies capable of simulating laboratory experiences",[6] there is no way to fully replace them.

Johnstone et al.[7] and Zaman et al.[8] studied the effectiveness in prelabs for preparation for laboratory sessions. Both reported that prelabs were beneficial to student comprehension and preparation. Barnes and Thornton[9] discussed that students who come to lab prepared have an increased understanding on the lab being performed. A deeper comprehension and interest in inquiry-based laboratories was supported through personal analysis and surveys.

Wyatt[10] examined the use of online prelabs in his biology class, supporting the pedagogy that electronic learning environments demonstrate a higher "academic achievement rate, engagement, and positive behavior" in students.[11] He found that students felt more engaged and had an easier time writing reports and answering post-lab questions after their implementation. A similar result was discussed by Koessler,[12] which was supported through personal surveys of the students and corresponding analysis. The online modules allowed students to receive immediate feedback relative to the traditional paper prelabs. Students were able to continually answer questions until they entered the correct response. Much like Russell's[13] incorporation of technology to benefit lectures, our prelab software was meant to enhance the students' overall experience and comprehension in the classroom; it was not meant to replace the fundamental role of hands-on laboratories.

Received: May 27, 2016
Revised: September 24, 2016

DOI: 10.1021/acs.jchemed.6b00394
J. Chem. Educ. XXXX, XXX, XXX−XXX

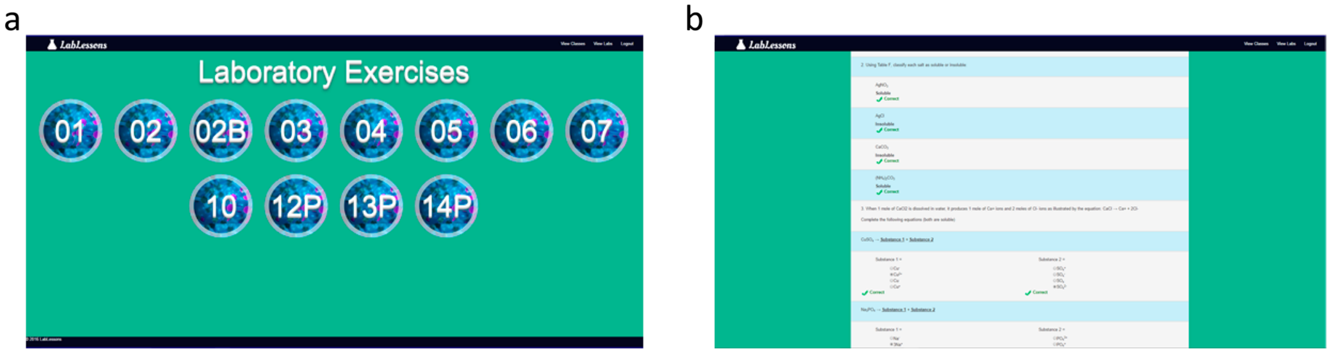

Figure 1. (a) Screenshot of the main page with all prelab content listed for LabLessons. (b) The instant responses to questions answered for the online prelab.

THE ONLINE PLATFORM: LABLESSONS

LabLessons[14] is an online Web site that delivers modules and prelabs (Figure 1a). The landing page of the site has a login for the individual students to sign in to their personal accounts on LabLessons. Upon logging in, students are presented with a selection of available prelabs that they can complete. Clicking on a listing in this selection takes the student to that respective prelab activity. The content and format for each prelab is dictated by the paper prelab prepared by the class instructor and does not have strict formatting rules. However, the typical format we have implemented is a textual introduction of the lab's key topics, followed by questions on those topics, and a computer simulation related to the laboratory experiment. Questions follow the paper prelabs as closely as possible. Upon answering questions, students are able to submit their answers and receive instant results as to whether or not their answers are correct (Figure 1b). They can then attempt to answer the questions again in order to attain the correct answer. The simulations with each prelab include both interactive sandboxes and guided visualizations. The interactive sandbox is designed to allow students to run through virtual equivalents of the lab experiment they will be performing and manipulate factors that enable them to achieve different results and draw conclusions off of them, whereas the guided visualizations lead students through the steps of the experiment they will be performing with an emphasis on the chemical changes occurring.

The user authentication, content delivery, and interactive questions of LabLessons are programmed in php and using a MySQL database. Though content is presented through html and css, the interactive components are handled by the server-side scripting language (php). The shared servers that host the Web site have either 32 Core AMD Opteron Processors 6376 or Intel(R) Xeon(R) CPUs E5-2630 v3, 64GB/32GB RAM, 4 RAID 1s, SSD MySQL, and a connection speed of 100 Mbps for both uploading and downloading. With this configuration, we have not experienced any load based troubles. However, it should be noted that as our system is a prelab system, users are completing their work at their leisure, thus the system rarely encounters significant numbers of concurrent users.

By creating LabLessons as an interactive Web page, we aim to make it more accessible to students than a native application tied to a specific platform. As such, students can log into LabLessons from any browser, be it on their computer, phone, or tablet, and are able to access their prelab content and answer assigned questions. Our content delivery system allows for teachers to deliver not only textual content including appropriately formatted formulas, but also images, embedded videos, embedded flash applications, and our own visualizations and simulations.

Our designed visualizations and simulations were built on the Unity game engine. We employed the Unity engine's new feature to build to WebGL. We added the ability to add WebGL apps to laboratories, ensuring that all modern browsers are capable of viewing the visualizations and simulations without any additional installations or troubleshooting.

DESIGN OF THE EXPERIMENTS FOR STUDENTS

Online, interactive modules were created for high school students at Brooklyn Technical High School in the Regents General Chemistry class. A team of two college students and a high school science teacher worked together to develop the modules to monitor content of the prelabs and to proctor quizzes/surveys.

Online prelab modules were designed by the two undergraduate students based off the content provided by the teacher. In addition, quiz questions were developed by both college students. The online prelabs were designed for five different laboratories and run for two separate laboratories: Solubility and Blueprinting (*vida infra*). Two different classes, an experimental class and a control class, were established to test the effectiveness of the online prelabs. The control class performed the lab on the same day as the experimental class in an effort to minimize changes in the teacher's day-to-day performance. The experimental class consisted of 15 male and 12 female students with 11.11% of the students from an African American demographic and 14.81% of the students from the Hispanic demographic. The control class consisted of 19 males and 14 female students with 6.06% of the students representing the Hispanic demographic. All participants were required to have parental consent to participate in the study design, enabling us to report feedback from the high school students (Supporting Information Figure S1).

Prior to entering the lab, the experimental class was assigned online prelab modules, whereas the control class was assigned a written prelab with the same content. Students of the experimental class were given a pre-quiz before the Blueprinting prelab to test their knowledge on the subject. Upon completion of both the Solubility and Blueprinting laboratories, students from both the control and experimental groups were given post-quizzes to determine the level of understanding that they gained throughout the lab. Students from the experimental group were given their prelab results instantaneously, and the control group was given their paper prelabs back after the post-

DOI: 10.1021/acs.jchemed.6b00394
J. Chem. Educ. XXXX, XXX, XXX−XXX

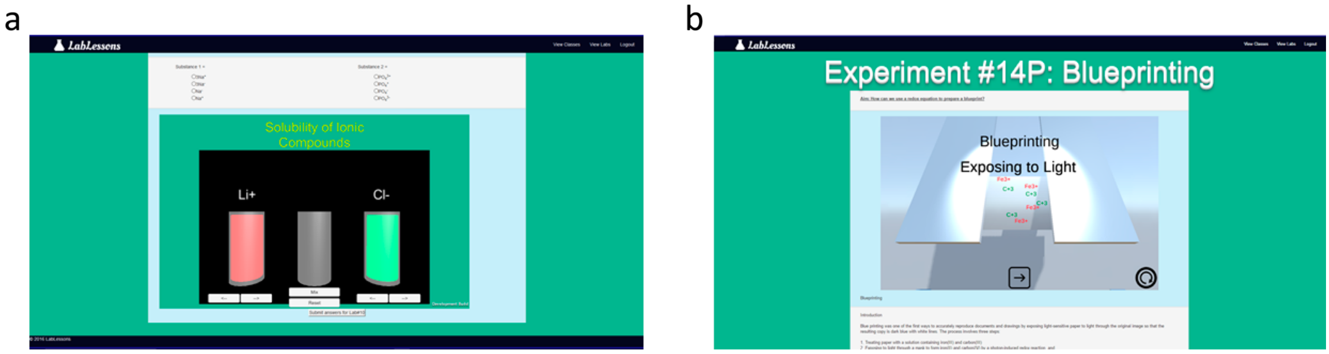

Figure 2. (a) Screenshot of the simulation for the solubility experiment. (b) Screenshot of the simulation for the blueprinting experiment.

Table 1. Comparison of Quiz and Lab Results

Experiment	Comparison	First Score	Standard Error of the Mean	Second Score	Standard Error of the Mean	*t* Test
Solubility	Post-Quiz Control vs Experimental	93.1	4.30	96.1	1.81	0.65
Solubility	Lab Grades Control vs Experimental	87.7	1.04	91.2	1.22	
Blueprinting	Pre-Quiz vs Post-Quiz Experimental	93.33	4.22	95.83	0.12	0.59
Blueprinting	Post-Quiz Control vs Experimental	86.67	4.33	95.83	0.12	
Blueprinting	Lab Grades Control vs Experimental	90.6	1.57	95.2	1.46	

quiz was given to the students upon grading completion from the teacher.

MODULES: SOLUBILITY AND BLUEPRINTING

The prelab for the "Solubility of Ionic Compounds" laboratory exercise focused on introducing students to the concepts of precipitation reactions and double-replacement (Supporting Information, Figure S2). The online prelab was designed with the goal of following the paper version as closely as possible. The online prelab was composed of three distinct parts: an introduction, questions, and a simulation of the lab experiment.

The introductory section of the online prelab was identical to that of the paper prelab. It first stated the aim of the lab, which was to determine the solubility rules of ionic compounds, then listed the solutions that the students would be using in the actual lab. This was followed by a paragraph that introduced and explained precipitation reactions and detailed the reaction of $AgNO_3(aq)$ and $NaOH(aq)$, a reaction that students would reproduce in the lab.

The questions section contained the first difference between the paper and online prelabs. Though the three questions presented were the same, the key difference was that the online version would identify correct and incorrect answers for the second and third questions. Thereby allowing the students to immediately identify mistakes. The first question, a written response, was graded by the instructor for both versions.

The second difference was that the online prelab showcased an interactive simulation. The simulation presented students with a number of solutions that they could virtually mix together (Figure 2a). When mixed, these solutions presented potential chemical results including precipitation, effervescence, no reaction and density separation, and the formation a new solution without precipitate.

The prelab for the "Blueprinting" laboratory exercise focused on introducing students to the chemical reactions behind the blueprinting process, specifically oxidation−reduction reactions (Supporting Information Figure S3). The online prelab for Blueprinting was designed with the goal of following the paper version as closely as possible.

As in the Solubility online prelab, another difference was the integration of a simulation. The simulation in this case was a visualization of the chemical processes that occurred within the steps of the laboratory experiment. The visualization went through each step that the students would perform during the lab and showed the chemical formulas present, and helped students better tie the oxidization−reduction reactions with the steps they were performing (Figure 2b).

RESULTS

For the Solubility module, both control and experimental students were given a written post-quiz related to the topic after carrying out the prelab and lab (Supporting Information, Figure S4). The quizzes consisted of three questions with one question being a two-part answer for a total of four possible points. While the control group scored a 93.14% with a standard error of the mean of 4.30, the experimental group demonstrated an increase with an overall score of 96.15% with a standard error of the mean of 1.81 (Table 1). A two-sample *t* test was run for the comparison resulting in a value of 0.65. These results illustrated that the experimental group did in fact have a higher retention rate than that of the control group.

In an attempt to further test whether the online prelab helped the students, a pre-quiz was added prior to carrying out the prelab for the second Blueprinting module (Supporting Information, Figure S5). The addition of the pre-quiz would be able to test whether or not the students from the experimental group better understood the topic at hand after carrying out the electronic prelab. The pre-quiz consisted of three questions based on the topic as the post-quiz did for both the experimental and control groups. The pre-quiz from the experimental group scored a 93.33% with a standard error of the mean of 4.22 (Table 1). After the pre-quiz a post-quiz was given to both the control and experimental group (Supporting Information, Figure S6). The post-quiz scores for the experimental were 95.83% with a standard error of the mean of 0.1, whereas those of the control group were 86.67% with a standard error of the mean of 4.33 (Figure 5). A two-sample *t* test was run for the pre-quiz and post-quiz comparison between

DOI: 10.1021/acs.jchemed.6b00394
J. Chem. Educ. XXXX, XXX, XXX−XXX

the quizzes performed by the experimental group and resulted in a value of 0.59. This demonstrated that the experimental group had a high retention rate and that they better understood the topic after the online prelab than they did before the lab.

It can be observed that the experimental group performed better than the control group on the post-quiz in both cases. The experimental group outperformed the control group in both modules. The experimental group also appeared to better understand the topic at hand due to use of the online prelab.

In addition to the pre- and post-quizzes for the Blueprinting laboratories, the students were also given surveys (Supporting Information, Figure S7, Table 1, Box 1) to ask them questions

Box 1. List of survey questions for students

How well did you know the topic at hand before performing the experiment?

How well did you know the topic at hand after having performed the experiment?

Did the simulation help with visualizing the concepts?

How likely would it be for you to recommend this system for someone learning about rates of reactions?

Which part in particular from the simulation did you most enjoy?

Was there any part of the simulation that taught you something you were previously struggling with? If so, which part?

How easy was it to operate the system?

Do you feel that this experiment would have been more difficult to understand without the use of the simulation?

about their use of the system on a 1−10 scale (1 being the worst and 10 being the best). One question asked them how they felt they understood the topic at hand before and after using the online prelab. The response consisted of all but 7 students out of 23 total feeling they understood it better (Figure 3). The 7 students who did not feel better about it indicated no change in understanding with a 10 ranking before and after the online module. These were averaged out to show that the topic was understood with an average of a 7.3 with a standard error of the mean of 1.04 compared to an overall understanding of a 9.3 with a standard error of the mean of 0.19 out of 10 after using the online prelab (Figure 4). These figures show a direct contribution to the individual learning for the students involved in the experiment.

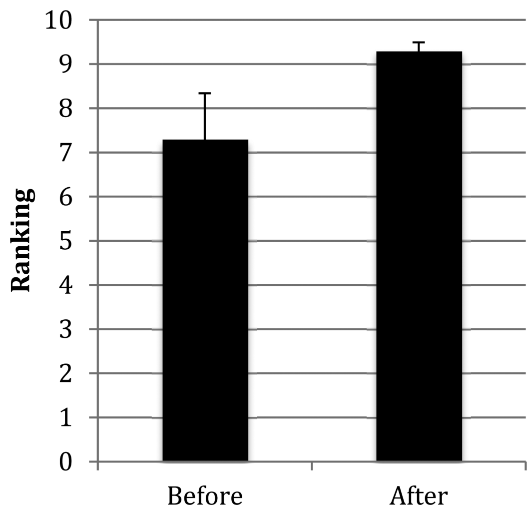

Figure 4. Average rankings of all 23 students on a scale of 1−10 for how well they understood the topic before and after the experiment with error bars representing the standard error of the mean. The ranking shown is a student self-reported sense of mastery of the material.

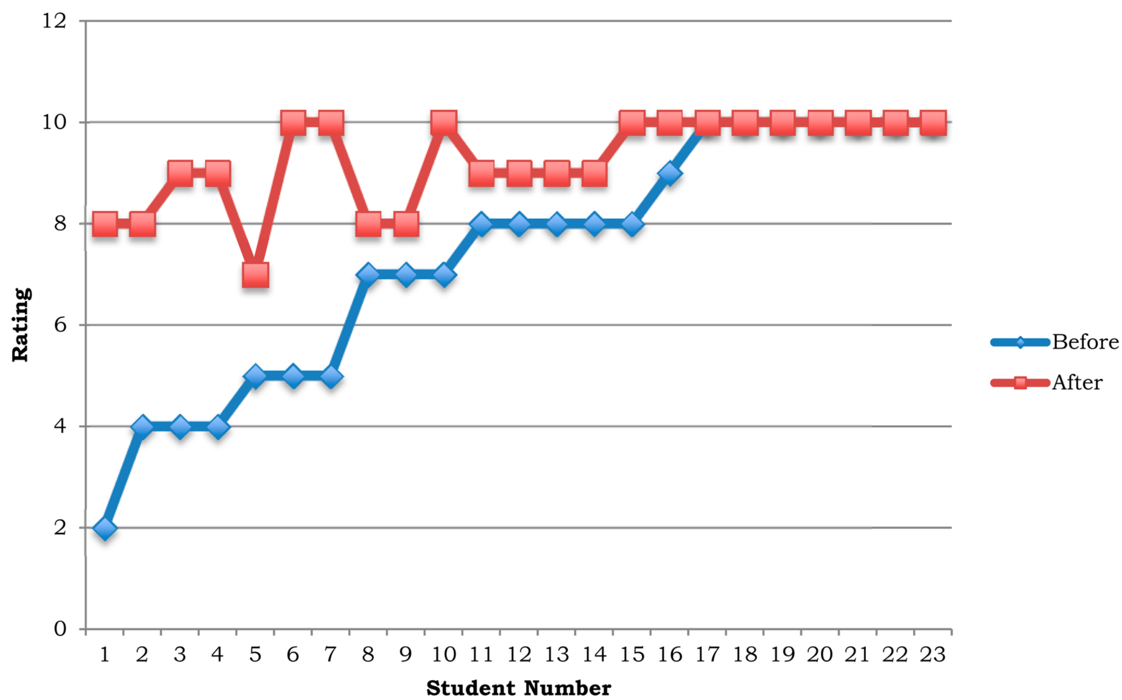

Figure 3. Ranking on a scale of 1−10 for how well each individual student understood the topic before and after the experiment. The ranking shown is a student self-reported sense of mastery of the material.

DOI: 10.1021/acs.jchemed.6b00394
J. Chem. Educ. XXXX, XXX, XXX−XXX

An additional question was asked of them in a "Yes" or "No" format on how they felt the online prelab helped with understanding the concepts and impact on performing the experiment. In regards to making the concepts easier to understand, 20 of the students, or 86.96%, agreed that the online prelab helped, whereas 2, or 8.70%, did not reply, and only 1, or 4.34%, who did not (Table 2). For performing the experiment easier, 20 of the students, or 86.96%, agreed that the online prelab helped, whereas only 3 of the students, or 13.04%, did not (Table 2). The numbers show that the students did in fact find the online prelabs to be beneficial.

Table 2. Comparison of the Survey Results

Survey Question	Total Students	Total Students to Reply "Yes"	Total Students to Reply "No"	Total Students to Not Reply
Whether or not the simulation helped with understanding the concept.	23	20	1	2
Whether or not the simulation made performing the experiment easier.	23	20	3	

In addition to these findings, the students also seemed to perform better in the actual laboratory, which was subsequently corroborated by the teacher. Students performing the solubility experiment using the online platform received an overall average of 91.2% with a standard error of the mean of 1.22, whereas the control class only scored 87.7% with a standard error of the mean of 1.04 (Table 1). The same was done for the overall grades for the laboratory for the blueprinting experiment. The experimental group scored a 95.2% with a standard error of the mean of 1.57, whereas the control group only scored a 90.6% with a standard error of the mean of 1.46 (Table 1).

In addition to the students' responses, the teacher answered survey questions based on the Blueprinting experiment (Supporting Information Figure S8, Table 2, Box 2). He believed that on a scale of 1−10, the students enjoyed it at about a "9" because of the number of viewings and the helpfulness of the interactive graphics. He also found that the online prelabs seemed to speed up the actual lab because of the better preparedness with which his students came into the class. This allowed for less time used for answering questions about the experiment. He also gave the online prelabs a "10" on ease of use for both his students and himself. The teacher also found that the students performing the experiment using LabLessons finished the experiment more efficiently and in a quicker time frame than the control class did. This was believed to be due to the better preparation and better understanding of what was happening in the laboratory by the students. Overall, the online prelab appeared to be a very helpful tool in assuring that the students knew what to expect in the experiment, both conceptually and operationally.

Box 2. List of survey questions for teacher

How do you feel the students seemed to enjoy using the system?

How did you enjoy using the system?

Did using the technology seem to speed up the experiments or slow them down?

Did the class seem to be more prepared or less prepared for the experiment after using the system?

How easy was the system for you to use?

How would you improve the content for this experiment?

■ DISCUSSION

The students in the experimental group performed slightly better than the students in the control group based on the post-quizzes given to both classes. Moreover, the teacher found that the lab was more efficient because the students in the experimental group were more prepared than the control group. This could be attributed to the students having to complete the prelab in full before coming to class, whereas students with paper copies would rush it beforehand. This further supported the goal of using technology to sustain student interest and promote learning.[4] In addition to performing better than the control group in terms of the post-quizzes, the students in the experimental group scored better than the control group on the statewide Regents Chemistry examinations. The overall score for the experimental group for this was a 79.23% with a standard error of the mean of 1.97; meanwhile, the overall score for the control group was a 77.34% with a standard error of the mean of 1.80 (Figure 5).

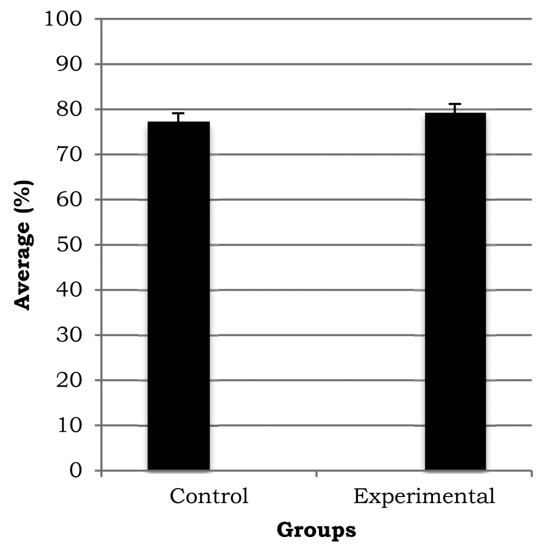

Figure 5. Overall scores on the Regents Examinations for the experimental and control groups with error bars representing the standard error of the mean.

A two-sample t test was run comparing the two scores and resulted in a 1.10. This illustrated that the students in the experimental group retained the information over a longer period than the control group did. The comparison between the experimental group and previous classes also showed that the experimental group had in fact improved (Figure 6). The 2014 class, which had 1,281 students, scored an overall average of 79.21% with a standard error of the mean of 0.26 on the Regents Examination. The 2013 class, which had 1,304 students, scored an overall average of 78.76% with a standard error of the mean of 0.26 on the Regents Examination. Ensuring that the students were not simply improving over time, the overall average of all students was run for the 2015 class with a total of 1,321 students which was a 78.64% with a standard error of the mean of 0.26. This helps to support that

DOI: 10.1021/acs.jchemed.6b00394
J. Chem. Educ. XXXX, XXX, XXX−XXX

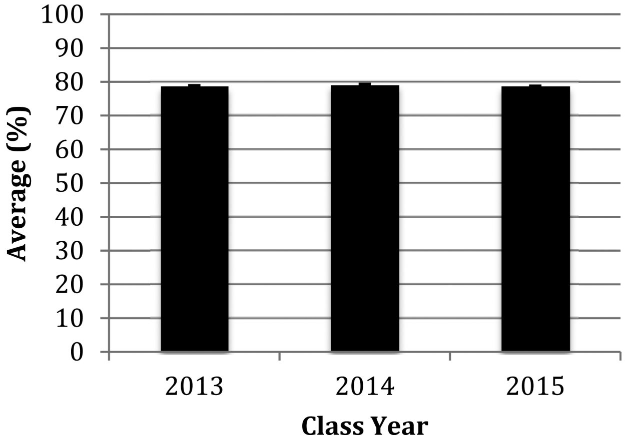

Figure 6. Overall scores on the Regents Examinations for the previous three years.

the students were in fact gaining a mastery of the content material. The mastery of the content helped them to perform better on the Regents exams.

PROGRAM OUTCOMES

The experimental run of LabLessons proved to show significant improvement for the students as an overall learning experience. More prelabs are being designed for the benefit of high school students. Eventually, the entirety of a year's high school chemistry curriculum should be accessible through LabLessons as online prelabs. Additional experimental runs will hope to further the conclusion that technology, such as LabLessons, does in fact help high school students.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.6b00394.

Information about the required consent forms for students to sign, the prelab for the solubility experiment, the prelab for the blueprinting experiment, the post-quiz for the solubility experiment, the pre-quiz for the blueprinting experiment, the post-quiz for the blueprinting experiment, the survey for the students for the blueprinting experiment, and the survey for the teacher for the blueprinting experiment. (PDF)

Information about the required consent forms for students to sign, the prelab for the solubility experiment, the prelab for the blueprinting experiment, the post-quiz for the solubility experiment, the pre-quiz for the blueprinting experiment, the post-quiz for the blueprinting experiment, the survey for the students for the blueprinting experiment, and the survey for the teacher for the blueprinting experiment. (DOCX)

AUTHOR INFORMATION

Corresponding Author

*E-mail: montclare@nyu.edu.

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

We thank Carlo Yuvienco and Nicholas Almodovar for their assistance on this work. This program was supported by the Teagle Foundation, National Science Foundation (NSF, DMR-1205384 and DMR-1505214) as well as by the MRSEC Program of the NSF under Award Number DMR-0820341.

REFERENCES

(1) Tobin, K. Research on science laboratory activities: In pursuit of better questions and answers to improve learning. *Sch. Sci. Math.* **1990**, *90* (5), 403−418.
(2) Supon, V. Cursive Writing: Are Its Last Days Approaching. *J. Instr. Psychol.* **2009**, *36* (4), 357−359.
(3) Wallace, R. R.; Schomer, J. H. Simplifying Handwriting Instruction for the 21st Century. *Education* **1994**, *114* (3), 413−417.
(4) Lewis, M. S.; Zhao, J.; Montclare, J. K. Development and Implementation of High School Chemistry Modules Using Touch-Screen Technologies. *J. Chem. Educ.* **2012**, *89* (8), 1012−1018.
(5) Kim, H.; Chacko, P.; Zhao, J.; Montclare, J. K. Using Touch-Screen Technology, Apps, and Blogs To Engage and Sustain High School Students' Interest in Chemistry Topics. *J. Chem. Educ.* **2014**, *91*, 1818−1822.
(6) Chacko, P.; Appelbaum, S.; Kim, H.; Zhao, J.; Montclare, J. K. Integrating technology in STEM education. *J. Technol. Sci. Educ.* **2015**, *5* (1), 5−14.
(7) Johnstone, A. H.; Zaman, T. U.; Watt, A. The students' attitude and cognition change to a physics laboratory. *Phys. Educ.* **1998**, *33* (1), 22−29.
(8) Zaman, T. U. *The Use of Information Processing Model to Design and Evaluate a Physics Undergraduate laboratory*; Center for Education, Glasgow University: Glasgow, U.K., 1996; pp 1−201.
(9) Barnes, R.; Thornton. Preparing for laboratory work. In Black, B.; Stanley, N. *Teaching and Learning in Changing Times*; The University of Western Australia: Perth, Australia, 1998; pp 28−32.
(10) Wyatt, R. Campus Technology: Online Biology Pre-Labs. http://campustechnology.com/articles/2003/05/online-biology-prelabs.aspx (accessed Jul 2015).
(11) Kaufman, W. T. Traditional vs. Electronic Environment. Master's Thesis, The College at Brockport: State University of New York, 2015.
(12) Koessler, K. C. Effects of Online Prelab Activities on Success in Laboratory Exercises in the Science Classroom. Master's Thesis, Montana State University, 2014.
(13) Kozma, R. B.; Russell, J. W.; Jones, T.; Wykoff, J.; Marx, N.; Davis, J. Use of Simultaneous-Synchronized Macroscopic, Microscopic, and Symbolic Representations To Enhance the Teaching and Learning of Chemical Concepts. *J. Chem. Educ.* **1997**, *74* (3), 330.
(14) LabLessons. http://www.lablessons.com/ (accessed Aug 2016).

DOI: 10.1021/acs.jchemed.6b00394
J. Chem. Educ. XXXX, XXX, XXX−XXX