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Improving and Assessing Student Hands-On Laboratory Skills through Digital Badging

Sarah Hensiek,[†] Brittland K. DeKorver,[‡] Cynthia J. Harwood,[†] Jason Fish,[§] Kevin O'Shea,[§] and Marcy Towns*[,†]

[†]Department of Chemistry, Purdue University, West Lafayette, Indiana 47907, United States
[‡]Lyman Briggs College, Michigan State University, East Lansing, Michigan 48825, United States
[§]Teaching and Learning Technologies, Purdue University, West Lafayette, Indiana 47907, United States

Supporting Information

ABSTRACT: Building on previous success with a digital pipet badge, an evidence-centered design approach was used to develop new digital badges for measuring the volume of liquids with a buret and making a solution in a volumetric flask. These badges were implemented and assessed in two general chemistry courses. To earn the badges, students created videos of their techniques at the end of lab and uploaded them using the Passport app. Students received individual feedback from their instructors and were able to attempt the technique again if their first performance was unsatisfactory. To evaluate the badge as a laboratory assessment tool, students completed surveys about their knowledge, confidence, and experience using each technique with a retrospective-pre then post survey design. Analysis of these surveys showed statistically significant gains in student knowledge, confidence, and experience across both courses and both badges. Student performance on exams and procedural questions within the badges supports the conclusion that the badges positively impacted student learning of these two techniques. This research establishes that a digital badging approach can be used to improve student hands-on skills across multiple techniques and multiple student populations.

KEYWORDS: *First-Year Undergraduate/General, Chemical Education Research, Curriculum, Laboratory Instruction, Testing/Assessment, Laboratory Equipment/Apparatus*

FEATURE: Chemical Education Research

Research has demonstrated that mastery of hands-on laboratory skills and techniques is an important goal in the undergraduate chemistry laboratory curriculum.[1,2] These skills cannot be learned in lecture and are important for students who wish to pursue careers in chemistry or related STEM fields. Without an understanding of lab techniques, students cannot precisely and accurately collect and analyze data. This compromises their ability to generate plausible explanations based upon experimental evidence and to appreciate the context for chemistry problems they encounter in their coursework.

Laboratory techniques, such as using a buret to make precise volumetric measurements and using a volumetric flask to accurately prepare solutions, are an important component of many experiments in introductory and advanced-level chemistry laboratory coursework. These skills require both physical dexterity and knowledge about the design and function of the equipment. Despite instructions in the laboratory manual or demonstrations by faculty or teaching assistants, many students unknowingly employ improper techniques. Thus, the measurements they obtain become less precise, impacting their calculations and the explanations they construct from their data. When students cannot trust their data, opportunities for learning in the lab are lost as students lose the ability to create meaning from the actions they carry out.

Unfortunately, the extent of this issue is concealed by the difficulty in assessing students' hands-on techniques. Many times, constraints on time or personnel resources limit the ability to assess hands-on laboratory skills during a laboratory period. Instead, students are assessed only on written lab reports. While these artifacts allow instructors to gauge errors in data collection, the source of those errors, such as poor technique, go unidentified and uncorrected. This problem is exacerbated in situations where students work in groups or submit group reports, as it provides little individual accountability for the students and limits opportunities for individual assessment and feedback. The lack of assessment of hands-on skills may lead students to believe that these skills are not valued in the laboratory curriculum.

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Digital badging provides an effective way to address some of these problems using an evidence-based approach. Instead of relying on an indirect assessment of students' technique via their reported data, instructors have the ability to monitor students' skills and provide appropriate individual feedback to improve their performance.

LITERATURE REVIEW

Student Learning in the Laboratory

Learning in the undergraduate laboratory has been the subject of much recent research.[1−7] Laboratory courses are generally thought of as an important part of the chemistry curriculum, but researchers have also questioned their value and have raised questions about the learning that occurs in these courses.[8−12] Kirschner and Meester state that students often receive inadequate feedback in the laboratory and that the design of laboratory courses generally does not support student learning of practical skills.[13] Other researchers echo the need for accountability and valid ways to assess lab skills through the development of rubrics.[14,15]

Previous research in the Towns and Bretz research groups has focused on faculty goals for undergraduate laboratory courses,[1−3] and more recently, research has been carried out to elucidate student goals.[5−7] A national survey of chemistry faculty revealed that learning hands-on skills was an important goal across the undergraduate chemistry curriculum.[2] Reid and Shah have also noted the importance of "practical skills" in the undergraduate laboratory.[9]

However, research has demonstrated that this is not an important goal for students, who tend to focus on more affective goals such as achieving satisfaction by finishing the lab quickly and getting better grades, resulting in negative consequences for their learning.[5] By using lab techniques that they believe are the fastest, or having their lab mates carry out the techniques for them, students maximize their own affective goals while avoiding learning the hands-on skills. As it has been posited that students may not learn things that are not aligned with their goals,[8] it is important to incorporate individual accountability for and assessment of hands-on lab skills into the laboratory curriculum.

Digital Badging

Digital badges are an effective way to showcase skills a student has learned while the badging structure itself provides the opportunity for evidence-based assessment of these skills.[16] Using badges as a form of credential is a common practice in many professional organizations. Perhaps the most well-known example is in scouting, where badges are awarded and worn to signify the completion of certain tasks or the mastery of specific skills. In order for a badge to have meaning, it must indicate specific, evidence-based inferences about the earner's knowledge, skills, and/or attitudes. Digital badges serve these same functions, but can extend beyond the boundaries of the awarding organization. Shared online, they can be connected to specific metadata about how the badge was earned (the criteria), who issued the badge, and with video evidence of the specific skills demonstrated in order to earn the badge.[17] Previously, a digital badge has been used as an approach to assess students' hands-on lab skills in pipetting.[18] The students gained experience with and received feedback on their performance of the technique, and as a result, their self-reported knowledge, confidence, and experience significantly improved. Furthermore, the badge design provided direct evidence to the instructors of the individual students' abilities through their videos. In order to explore the use of digital badging beyond the pipetting technique, digital badges need to be investigated and established in a variety of classroom contexts as well as across multiple techniques. This study seeks to evaluate use of digital badges with two other techniques commonly learned in the general chemistry laboratory: filling, reading, and using a buret and making a solution in a volumetric flask. Thus, the research questions are the following: (1) In what ways do digital badges impact student learning of hands-on lab skills related to burets and volumetric flasks? (2) How do digital badges support learning across different populations of students?

METHODS

To investigate the research questions, digital badges were created, implemented, and evaluated for properly using a buret and making a solution in a volumetric flask. Human subjects approval was obtained through Purdue University's IRB.

Digital Badge Design

The badges were designed using an approach similar to that used to create the pipetting badge.[18] Because badges must be connected to evidence-based inferences about student knowledge, evidence-centered design is an appropriate framework for developing badge activities. It allows instructors to identify specific constructs of knowledge, skills, and attitudes that students should be able to demonstrate, and then design badging tasks that allow students to demonstrate these constructs.[19,20] Appropriate constructs were identified by generating a list of important steps for each technique. These lists were developed and refined by chemists, course instructors, and teaching assistants according to best practices, with reference to the steps given in the appendix of the students' lab manual. These steps were incorporated into sets of instructions shown in Boxes 1 and 2 to guide students in creating their videos.

Box 1. Fall 2015 Student Instructions for the Buret Badge Video

Buret Video Instructions:

1. State your name and laboratory section number at the beginning of the video.
2. Properly clamp the buret and be sure the stopcock is closed.
3. Place a funnel in the top of the buret.
4. Pour the desired amount of solution into the buret and remove the funnel – do not start at 0 mL.
5. Do an initial straight-on, close-up shot of the meniscus (hold paper behind the buret).
6. Read the starting volume to the appropriate number of significant figures.
7. Use the stopcock to empty some liquid into an appropriate container.
8. Do a final straight-on, close-up shot of the meniscus (hold paper behind the buret).
9. Read the final volume to the appropriate number of decimal places.

Box 2. Fall 2015 Student Instructions for the Volumetric Flask Badge Video

Volumetric Flask Video Instructions:

1. State your name and laboratory section number.
2. Describe the volume of the flask you are using with the appropriate significant figures.
3. Add the appropriate amount of the solution you will be diluting to the volumetric flask.
4. Fill the flask with DI water from a beaker to about halfway up the neck of the flask.
5. Cover the flask with parafilm and invert to mix.
6. Use a medicine dropper to fill the flask so that the bottom of the meniscus is at the calibration mark. Do a close up shot of the calibration line.
7. Cover with parafilm and invert the flask to finish mixing.

Figure 1 is a still shot from a student's buret video showing step number 5 in Box 1, where the student is holding a piece of white paper behind the buret (thus, the buret is white) and is pointing to the meniscus. During the video the student would read the buret, and an instructor or teaching assistant could evaluate if the volume was correct and read to the proper precision. Figure 2 shows a student mixing a solution in a volumetric flask, which is associated with steps 4 and 7 in Box 2. While watching these videos an instructor or teaching assistant can evaluate if the

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Figure 1. A student demonstrates how to read a buret while creating a video to earn his Buret Badge. He is indicating the location of the meniscus while reading the volume of liquid in the buret.

Figure 2. A student demonstrates how to make a solution in a volumetric flask to earn her Volumetric Flask Badge.

proper procedures are used and if the student fills the volumetric flask to the correct level.

Student assessments of learning were used to evaluate the effectiveness of the badging project. A modified participant perception indicator (PPI) survey was created for each badge.[21] The PPI survey is based on the concept of self-efficacy[22] and focuses on what the students can do and what they believe they can do as a measurement of learning success. The psychometric properties of self-assessment instruments such as the PPI survey have been found to produce consistently reliable results, and there are persuasive results across contexts that self-assessment positively contributes to student learning.[23] Additionally, as Ross[23] noted, "Self-assessment contributes to self-efficacy beliefs, i.e., student perceptions of their ability to perform the actions required by similar tasks likely to be encountered in the future. (p. 6)" Thus, a self-assessment is an appropriate instrument to measure change and build self-efficacy of hands-on laboratory skills that will be used across the semester.

To increase the validity of the measure we used a retrospective-pre then post survey design (also known as retrospective gains[24]), where students evaluated their prior knowledge after completing the task. When compared with a pretask survey, the retrospective-pre survey gives a more accurate reflection of students' prior knowledge and attitudes,[25,26] due to the students' inability to recognize their own lack of knowledge prior to attempting a task.[18,27,28] Thus, the PPI is a valid measure for assessment of learning.

The PPI items were created to assess students' perceptions of their knowledge, confidence, and experience regarding various aspects of using a buret and a volumetric flask. The surveys included both identification and process statements that asked students to rate their knowledge (cognitive dimension), confidence (affective dimension), and experience (psychomotor dimension) on a five point Likert scale where 1 was low and 5 was high. The students were given an example about making a cup of tea to demonstrate how the scales were used. For instance, a student could indicate that she knew how to make a cup of tea (scoring 5 for the cognitive dimension), was confident in her ability to make a cup of tea (reflected by a 5 for the affective dimension), but had little experience in making a cup of tea (denoted by assigning a score of 2 for the psychomotor dimension). In addition to the PPI, a true/false question and a multiple-choice question related to students' knowledge of the technique were implemented on the buret badge to target two misconceptions that were revealed during pilot testing: students incorrectly believed that the buret must be filled to the 0 mL mark for the initial volume reading and were unaware of the precision of the buret. Thus, the two questions on the post survey are designed to test their knowledge. The survey items for each badge are shown in Boxes 3 and 4.

Box 3. Participant Perception Indicator survey questions for the Buret Badge.

Statement	Knowledge Low High	Experience Low High	Confidence Low High
1. Identify a buret from among pieces of glassware.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2. Properly clamp a buret.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
3. Correctly fill a buret with solution.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
4. Correctly read the volume of liquid in a buret to the correct number of decimal places.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
5. Use a buret to measure and dispense a volume of liquid.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Maximum score for each domain = 25

6. *True/False In order to get accurate measurements when using a buret, the liquid must start at the 0 mL mark (i.e. the buret is full).

7. *To what degree of precision should you read the volume of a buret?

a. To the nearest 1mL
b. To the nearest 0.1mL
c. To the nearest 0.01 mL
d. To the nearest 0.001 mL

* Only included in post survey

Box 4. Participant Perception Indicator survey questions for the Volumetric Flask Badge.

Statement	Knowledge Low High	Experience Low High	Confidence Low High
1. Identify a volumetric flask from among pieces of glassware.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2. Identify the calibration line on a volumetric flask.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
3. Properly fill a volumetric flask to prepare a solution.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
4. Know the volume of a volumetric flask to the appropriate decimal place.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Maximum score for each domain = 20

Implementation in Chemistry 11100

Chemistry 11100 is a first semester general chemistry course with a lecture and required laboratory. It primarily serves students in the College of Health and Human Sciences and the College of Agriculture with an enrollment of approximately 1000 students. The results of a 2012 survey implemented in Chemistry 11100 revealed that 30% of the students had completed five or fewer chemistry laboratories in high school. Thus, nearly one-third of the class has had limited experience engaging in hands-on chemistry laboratory activities and deserves particular attention

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to development of hands-on laboratory skills such as the digital badging approach.

The flow of activities to earn a digital badge is shown in Figure 3 where the students complete the tasks in the purple boxes and

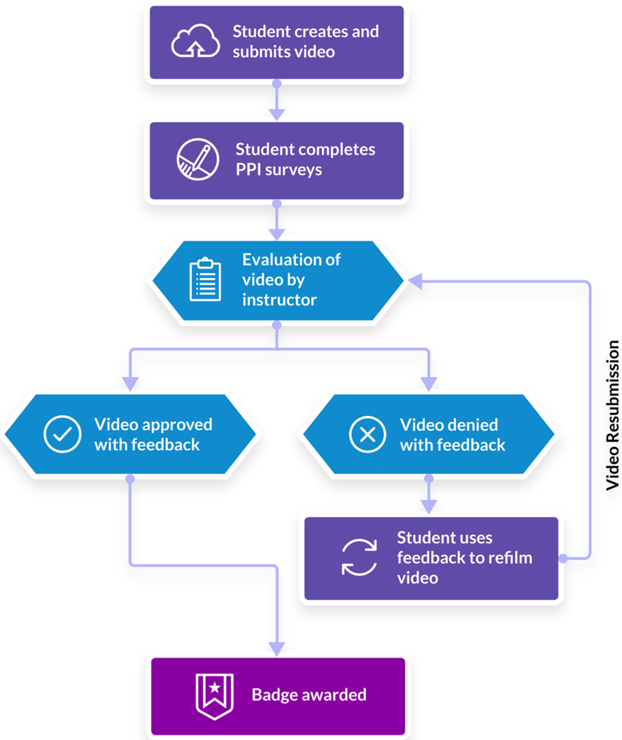

Figure 3. Flow of activities in earning a digital badge where the student completes the purple squares and the instructor completes the aqua hexagons.

the instructors complete the tasks in the aqua hexagons. The volumetric flask badge was made available to the students for 2 weeks, beginning during the third lab session of the semester. At the end of the experiment each student created a video in the laboratory using their own device (usually a phone or tablet) for filming following the instructions in Box 2. Each student submitted his or her video through the Passport app.[29] Then, the student completed the retrospective-pre and post PPI surveys within the Passport app as shown in Figure 3.

An instructor or teaching assistant evaluated each student video using the steps in Box 2 as criteria and gave individual feedback on the student's technique via a textbox within the app and designated the video as approved or denied as shown in Figure 3. If denied, the student could use the feedback to improve his/her technique and subsequently film a new video during the next laboratory period. This video could be submitted for evaluation as shown in the video resubmission loop on the right side of Figure 3.

Evaluation of the videos using the instructions in Box 2 as criteria was discussed with teaching assistants during a staff meeting to normalize the evaluation across all sections in the course. Sample feedback statements to the students were discussed with an emphasis on identifying mistakes and improving the student's technique. For example, if a student filled the flask above the calibration line and then poured out the excess and added solvent back in so that the meniscus was at the calibration line, the video was denied, and the teaching assistant recommended adding the solvent slowly with an eye dropper to reach the calibration mark. For approved videos, the teaching assistants gave positive feedback indicating that the student used the correct technique. Evaluating a lab section of 24 videos required between 45 and 75 min. The teaching assistants noted that they were able to evaluate the videos faster as they became more experienced.

The buret badge was implemented in Chemistry 11100 at the ninth lab session and was also available for 2 weeks. Implementation of the buret badge followed the same steps as shown in Figure 3. A discussion was held in staff meeting with the teaching assistants to normalize the grading across sections. The instructions in Box 1 were used as criteria for evaluating the videos. For example, if a student did not read the initial or final volume correctly, the teaching assistants were told to deny the video and give helpful feedback to the student indicating that the buret should be read from the top down to the correct number of significant figures. Teaching assistants required the same range of time to evaluate 24 videos in a laboratory section and similarly noted that the time to evaluate videos decreased as they gained experience.

A badge was awarded to a student after a video was approved and both PPI surveys were completed. Each badge was worth five points out of 1000 points in the course.

In addition to the student self-assessment of learning, an independent measure was used to evaluate students' understanding of using the glassware through examinations. Multiple-choice questions relating to reading and using a buret and making a solution in a volumetric flask were included on the second and third examination and the final. All examinations include questions about the laboratory since it is a required part of the course.

Implementation in Chemistry 11600

Chemistry 11600 is a second semester general chemistry course with a required lecture, laboratory, and recitation primarily for students in the College of Science and College of Engineering. The enrollment in the fall semester was approximately 420. The students in this course have taken prior college chemistry courses and/or have had one to two high school high school chemistry courses, which provides them with a greater degree of experience with hands-on laboratory techniques and various pieces of glassware than the Chemistry 11100 students.

The buret badge was implemented in Chemistry 11600 at week seven and remained available for 4 weeks due to a holiday break in the academic calendar. As with Chemistry 11100, this allowed students whose initial videos were denied to film another video for submission after reflecting on the feedback they received from their instructors. The implementation followed the same pattern as shown in Figure 3, and the badge was worth 5 points out of 1050 points in the course.

Analysis

For each badge implemented in a course, summing the students' responses for knowledge, confidence, and experience for the retrospective-pre and post-test survey resulted in three pairs of composite scores to be compared. The assumption of normality for each composite score was tested using the Kolmolgorov–Smirnov test. If nonparametric tests were indicated, then they were carried out, and the appropriate effect size measures were calculated. Effect size measures for nonparametric statistics are somewhat less intuitive since they are not as easily interpreted as a Cohen's *d* which is measured in units of standard deviation or the pooled standard deviation. However, given that for large

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Table 1. Results for Chemistry 11100 Buret Badge PPI surveys

Survey	Mean[a] (N = 681)	Standard Deviation	Z Value[b]	Effect Size Measure
Knowledge RetroPre	16.13	6.81	−19.1	0.52
Knowledge Post	22.64	2.98		
Confidence RetroPre	16.39	6.67	−18.9	0.51
Confidence Post	22.64	2.97		
Experience RetroPre	15.28	7.17	−19.1	0.52
Experience Post	22.14	3.53		

[a]Maximum value of 25. [b]Significant at $p < 0.001$.

sample sizes statistical significance is often found, it is important to comment upon the practical importance through effect size measures. A summary of responses to individual questions for all survey items across both badges is presented in the Supporting Information. The percentage correct was calculated for all multiple-choice examination questions.

Validity and Reliability

The method of creation of the PPI instruments and badging instructions supports their validity. Chemistry instructors and chemistry education researchers referenced best practices and the students' laboratory manual instructions to ensure content validity of the PPI items and instructions for badging. Reliability of the PPI was assessed using Cronbach's α. The surveys for both badges showed high reliability (buret $\alpha = 0.944$, volumetric flask $\alpha = 0.947$) likely due to the repetition of survey items across the three domains of knowledge, confidence, and experience as well as the very narrow scope of the items on each survey. Student self-assessment has been shown to be a reliable and valid technique especially when students understand the criteria used and the instrument focuses on performances they perceive to be important.[23]

■ RESULTS

Buret Badge

In Chemistry 11100, 681 out of 1013 students submitted an approved video and completed both the PPI surveys. Of those 681 students, 107 had their first video denied and resubmitted a revised video that was approved. To determine if the assumption of normality held, the Kolmogorov−Smirnov test was used. The results for the knowledge, confidence, and experience composite scores for the retrospective-pre and post survey indicated that the data was not normally distributed, as is often the case with Likert scale data.

A Wilcoxon Signed Ranks Test was used to analyze the scores, and the results are displayed in Table 1. The analysis indicates that the post-test scores are statistically significantly higher than the retrospective-pre scores for the students' self-reported knowledge, confidence, and experience. An effect size measure was calculated by dividing the Z value by the square root of the number of observations.[30] For each comparison, the effect size is large, greater than 0.50, and indicates a practical significance.

Table 2. Results for Chemistry 11100 Buret Badge Knowledge Question: To What Degree of Precision Should You Read the Volume of the Buret?

Response	Distribution of Responses (N = 681)
A. 1 mL	3.4%
B. 0.1 mL	23.1%
C. 0.01 mL[a]	72.2%
D. 0.001 mL	1.3%

[a]Correct response.

Given that some these students have not completed many laboratories it is interesting to identify the statements in the PPI with the largest changes. The item with the largest change was in the Experience domain, "use a buret to measure and dispense a volume of liquid". Looking across all three domains the single item that had the first or second largest change was "identify a buret".

As a part of the post survey two questions were asked related to students' knowledge of using a buret as shown in Box 2. For the true/false question regarding filling a buret, the 74% of students correctly answered that the buret does not need to be filled to the

Box 5: Question on the final exam requiring students (N=968) to calculate a final buret reading by reading the buret shown in the figure and performing a calculation. The distribution of responses is presented in parentheses and (d) is the correct response.

A student is ready to begin a titration using the buret set up shown below. What will be the buret reading after she dispenses 14.50 mL of solution from the buret?

(a) 7.85 mL (11.5%)
(b) 14.50 mL (1.2%)
(c) 21.00 mL (6.8%)
(d) 21.15 mL (73.3%)
(e) 21.85 mL (7.1%)

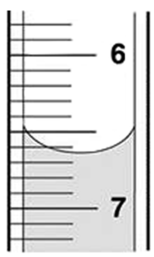

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Table 3. Results for Chemistry 11100 Volumetric Flask Badge PPI surveys

Survey	Mean[a] (N = 766)	Standard Deviation	Z Values[b]	Effect Size Measure
Knowledge RetroPre	14.18	4.19	−19.9	0.51
Knowledge Post	18.18	2.13		
Confidence RetroPre	14.27	4.09	−19.9	0.51
Confidence Post	18.17	2.19		
Experience RetroPre	13.47	4.48	−20.3	0.52
Experience Post	17.71	2.54		

[a]Maximum value of 20. [b]Significant at $p < 0.001$.

Table 4. Results for Chemistry 11600 Buret Badge PPI Surveys

Survey	Mean[a] (N = 270)	Standard Deviation	Z Values[b]	Effect Size Measures
Knowledge RetroPre	22.51	2.84	−8.0	0.34
Knowledge Post	23.59	2.30		
Confidence RetroPre	22.35	2.97	−7.9	0.34
Confidence Post	23.39	2.48		
Experience RetroPre	22.23	3.05	−8.3	0.36
Experience Post	23.34	2.60		

[a]Maximum value of 25. [b]Significant at $p < 0.001$.

0 mL mark obtain accurate results. The results of the multiple-choice question regarding the precision of a buret are summarized in Table 2, and 72.2% of the students responded correctly.

Questions about properly reading a buret were asked on exam three and on the final exam. On exam three 85% of the students correctly responded to a question that required reading the volume of liquid shown in a figure of a buret to the correct precision. The question appearing on the final is shown in Box 5. This item required the students to read the initial volume correctly, imagine dispensing 14.50 mL of liquid, then calculate the final volume. For this question, 73.3% of students answered correctly.

Volumetric Flask Badge

For this badge 766 students submitted an approved video and completed both PPI surveys. Among those 766 students, 39 had their first video denied and resubmitted a revised video that was approved. The knowledge, confidence, and experience composite scores were tested for normality using the Kolmogorov–Smirnov test. For each score on the retrospective-pre and post-test, $p < 0.001$ indicating that the data was not normally distributed as is often the case with Likert scale data.

Thus, a Wilcoxon Signed-Ranks Test was used to analyze the scores, and the results are shown in Table 3. The analysis indicates that the post-test scores were statistically significantly higher than the retrospective-pre scores for the students' self-reported knowledge, confidence, and experience. An effect size measure was calculated by dividing the Z value by the square root of the number of observations.[30] For each comparison, the effect size is large (greater than 0.50) and indicates a practical significance.

On exam two, a question was asked about the reason for inverting the flask several times when preparing a solution in a volumetric flask when the final small volume of solvent (water) was being added so that the bottom of the meniscus was at the calibration line. On this exam question, 94.7% of students answered correctly that it was to completely mix the solution.

Implementation in Multiple Courses: Chemistry 11600

To assess the badge's performance across courses, the buret badge was implemented in Chemistry 11600, a second semester general chemistry course serving students in the College of Engineering and College of Science. In total, 270 students completed the badge with usable survey and video data. Of that group, 109 students had their first video denied and resubmitted a revised buret video that was approved. As with the Chemistry 11100 data, the Kolmogorov–Smirnov test indicated that the data was not normally distributed; thus, a Wilcoxon Signed-Ranks Test was used. The analysis shown in Table 4 demonstrates that the post-test scores were statistically significantly higher than the pretest scores. The effect size measures were in the medium range.[30]

On the true/false question about buret knowledge (see Box 2), 79% of the 270 students correctly answered false. The results of the multiple-choice question regarding buret precision are shown in Table 5, and 82% responded correctly.

Table 5. Results for Chemistry 116000 Buret Badge Knowledge Question: To What Degree of Precision Should You Read the Volume of the Buret?

Response	Distribution of Responses (N = 270)
A. 1 mL	1.24%
B. 0.1 mL	15.22%
C. 0.01 mL[a]	82.61%
D. 0.001 mL	0.93%

[a]Correct response.

■ DISCUSSION

The results of this project demonstrate that digital badges can be used to assess multiple hands-on skills in general chemistry laboratory. The videos provided direct evidence of the students' hands-on skills with each piece of equipment, and served as documentation of their learning. Through this digital badging project, students received individual feedback and were able to improve their technique in a targeted manner.

Chemistry 11100 students reported large, statistically significant increases in knowledge, confidence, and experience for both badges. This finding corresponds well to this group of students' initial lack of experience in chemistry laboratory and their perceived increases after learning more about the

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equipment and how to use it. Chemistry 11100 students perceived substantial gains in their ability to identify and use the equipment.

The buret badge performed well across multiple course settings. The PPI retrospective-pre survey revealed that the Chemistry 11600 students started out with higher self-perceived knowledge, confidence, and experience than the Chemistry 11100 students. They also made statistically significant gains, which were smaller in magnitude than those of the Chemistry 11100 students, and revealed medium effect sizes. These results were expected and support the face validity of the students' self-assessment. Chemistry 11600 students have either taken one or two semesters of college chemistry and/or have taken one or two years of high school chemistry and had more opportunities to use laboratory equipment. Thus, the PPI survey performed as expected, supporting its use as a measure of the students' self-assessment of the constructs of identifying and using a buret, and measurement of the knowledge, confidence, and experience of different student populations. This analysis also demonstrates that badges can benefit students who have already had experience with a lab technique. The students did experience further improvement of their hands-on lab skills and have increased perceptions of success.

We noted in CHM 11600 for the buret badge that a higher percentage of students had their first video denied than in CHM 11000. The evaluation criteria were the same in both classes, and the evaluation criteria was discussed at staff meeting in both courses. Among the denied videos in CHM 11600, the most frequent mistake was reading the buret from the bottom up rather than the top down.

In both courses, a majority of students responded correctly that the initial volume reading of a buret does not need to be 0 mL. The majority of students were also able to identify the correct degree of precision to which a buret should be read. In conjunction with the self-reported data, this provides an objective benchmark with which the students' self-assessment of their knowledge about their hands-on abilities can be compared and provides further support for the efficacy of the PPI survey as an assessment tool. While these questions do not directly assess hands-on lab skills, the questions require procedural knowledge of how a buret is used in order to obtain the correct answer underscoring the utility of the digital badges as a teaching tool. Similarly, the examination results in Chemistry 11100 demonstrate that the majority of students could correctly read the volume of the buret and understood how it was used to measure the volume of liquids. The exam questions also provide evidence that knowledge of the use of a buret was retained throughout the semester.

Implications for Classroom Practice

Faculty can use badging in a variety of ways to support learning in courses. In the case of demonstrating proficiency in laboratory skills, faculty could choose to require that students obtain badges before moving on in the laboratory curriculum. For example, if students are using expensive or hazardous reagents or equipment, the faculty might choose to require that students earn a badge to demonstrate how to appropriately and safely use the equipment. In our case we did not require that students obtain a badge as a prerequisite for continuing to work in the lab. However, faculty could structure a course in that manner.

This project used the Passport app[29] from Purdue University, and we note that other types of digital badging apps and software exist such as Badge List, Badgr, Canvabadges, ForAllRubrics, or Peer 2 Peer University.[31] In this project we were fortunate to have colleagues in Teaching and Learning Technologies at Purdue who assisted us in setting up the badges within Passport and in handling any student use issues which emerged. Implementing a new teaching and learning technology requires time for piloting and troubleshooting. Summer sessions are an ideal time to carry out this activity and refine the implementation for fall semester. We encourage faculty to pilot a digital badge before implementing it in a course in order to test how the technology functions on various platforms and to troubleshoot the activity.

Within some badging platforms (including Passport), students can choose to make the badges they earn public demonstrating their skills and competence analogous to obtaining certification in professional specialties. We reviewed the data in this project and found that 1−2% of the students added their badges to a public profile. In this course there was no incentive to make the badges public. However, faculty could construct and implement a digital badging project wherein students earn badges and make them public for a specific purpose such as demonstrating skills that would be useful in a research laboratory or in the field. Faculty outside the course or employers could review the students' public badges including the videos and any other artifacts that students have included to provide evidence of their skills, knowledge, and abilities. This would give faculty and employers another method of evaluating students and could play a role in determining whether a student is offered an undergraduate research position, a research assistantship or internship, or a job interview.

Limitations

We note that there are limitations inherent to this study. One of the measures used in the study, the PPI, relies on student perceptions rather than observation of the students actually carrying out the technique, although the instructors viewed the videos in order to assess students' ability to carry out the technique. Additionally, the examination questions are used as a proxy to assess student knowledge of procedural skills rather than a laboratory practical.

■ CONCLUSIONS

We have established that digital badging is a valid and effective tool for evaluating hands-on laboratory skills. It is useful across the general chemistry laboratory curriculum over multiple hands-on laboratory techniques. Additionally at Purdue we have lowered our laboratory costs through decreasing the amount of equipment that is broken through improper use. Although we have used the Passport app[29] from Purdue University, other types of digital badging apps and software could be implemented.[31] Thus, this digital badging approach is adaptable and portable to other institutions.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.6b00234.

Summary of survey data for all badges (PDF, DOCX)

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: mtowns@purdue.edu.

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Notes

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