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Publisher Citation

iPads in the Science Laboratory: Experience in Designing and Implementing a Paperless Chemistry Laboratory Course, Journal of STEM Education, Volume 14, No. 2, 2013

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iPads in the Science Laboratory: Experience in Designing and Implementing a Paperless Chemistry Laboratory Course

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Introduction

New technology is constantly making its way into the classroom in an attempt to improve the learning experience (Melhuish, K. & Falloon, G., 2010). With society's current focus on STEM education and technology, there have been recent opportunities to incorporate technology into the learning process at all levels. Recently, more sophisticated video games, some on handheld devices, are making their way into to K-12 classrooms in an attempt to foster STEM skills for the next generation. Using technology in this manner is gaining increasing support as government leaders see this as a way of engaging more students in STEM disciplines and with 93 percent of schools having internet access, it makes the use of educational games a way to sparks students' interest in particular subject areas (Rowley, 2012; Center for Digital Education, 2012). The Technology Outlook for STEM + Education 2012-2017 (2012) anticipates this trend to continue and additionally be used to assess student learning in STEM topics. Johnson, Adams and Cummins (2012) stated, "games have proven benefits in engaging learners of all ages and helping them better understand complex material. Taking that notion one step further, simulations and game-based scenarios enable students to apply what they have learned in a realistic environment and receive instant feedback. Other uses, such as 3D model manipulations of macromolecules like DNA and proteins and the use of electronic white boards in elementary classrooms, illustrate the ways that new technology is being incorporated into the elementary classroom with an emphasis on science and engineering education (Center for Digital Education, 2012).

Video games as a learning tool are not limited to younger students. A 2009 article titled *Video Games: A Route to Large-Scale STEM Education* reported that video games could yield a 7 to 40 percent positive learning increase over a lecture program. Additionally, it supported its use as a benefit to poor learners with results proving to diminish the learning gap between learners by creating gaming systems that can adapt to the pace of the specific user and capitalize on the variation in learning styles (Mayo, 2009).

While not all technology is fun and games, students in higher education are increasingly connected to technological devices. A 2012 study showed that college-age students utilize at least three technological devices daily and that most students do not go more than an hour without using at least one of those devices. The same study reported that two-thirds of students would welcome an increased use of technology in the learning process, and many already utilize these devices for studying (Dunn, 2012). The more recent introduction of the iPad tablet into coursework provides a timely example of this trend. In addition to increasing use in the K-12 sector, the iPad is becoming an important academic tool in higher education (Johnson, L., Adams, S., & Cummins, M., 2012). Since its introduction, it has been incorporated into many college and university classrooms across the nation using different educational models (Raths, 2012; Marmarelli, T. & Ringle, M., 2011). St. Mary's University in Minnesota has introduced the iPad into its adult learning program. Duke University integrated the technology into its School of Nursing with a small group of students in the spring semester of 2012. The University of Minnesota

College of Education and Human Development distributed iPads to its entire freshman class of approximately 450 students at no cost to the students. In the fall of 2010, Seton Hill issued iPads to all full-time students and full-time faculty, with the goal of creating a mobile learning environment (Fuhrman, 2013). Oklahoma State University also created a pilot program which integrated iPad use into selected classes. Their 2012 report showed that the instructors involved, and 75 percent of students, believed the iPad provided an enhanced learning experience (Oklahoma State University, 2011). A goal for each of these initiatives was to evaluate new teaching technologies to facilitate student learning in the classroom setting.

To date, the use of iPads in college science laboratories has been limited. iPads have been used more and more often in academic research labs and in industry, as there has been considerable interest in these areas in creating digital or paperless laboratory systems (John D., Banaszczyk, M., & Weatherhead, G., 2011; Giles, J., 2012; Rubacha, M., Rattan, A.K. & Hosselet, S.C., 2011). The motivations for the introduction of a digital workflow in these laboratories include improved efficiency, increased productivity, improved data quality and immediate access to data. In classrooms and the laboratory, new pedagogical models are continually being developed, and encourage a wide range of technologies and tools to be imbedded into the course design. This is a trend that will continue to be tested and assessed, and will likely evolve as technology continually changes (Johnson, Adams, & Cummins, 2012).

In the fall of 2012, 20 General Chemistry Honors students at the University of New Haven were issued the iPad 3 to incorporate these devices in the classroom and the laboratory, and to expose students to experiences they will encounter in future careers (Samms, W.C. & Mozayani, A., 2012). This paper highlights this initiative to use iPads in the college laboratory environment. With the introduction of the iPad, an important goal was to create and implement a completely paperless lab; one in which no paper would enter the lab to record data or observations, or be used to complete and grade the final lab reports. It is important to note that the iPad was viewed as a device to facilitate the laboratory experience. We believe our experience with iPads in the General Chemistry Laboratory course can serve as an example of how such devices can be effectively used in a wide variety of science laboratory courses.

Abstract

In the fall of 2012, 20 General Chemistry Honors students at the University of New Haven were issued the new iPad 3 to incorporate these devices both in the classroom and the laboratory. This paper will focus on the integration of the iPad into the laboratory curriculum while creating a paperless experience, an environment where no paper would enter or be used for the laboratory over the course of the year. Specific apps were chosen that would allow for an easy transition of course materials into an electronic format. After a transition period for the students and instructor, the overall experience has been a positive one and can easily be implemented into any teaching laboratory.

Recommended Apps

Considering the availability of many inexpensive apps for education, communication and analysis of data, a significant effort was dedicated to choosing appropriate applications. New apps are launched frequently. Effort was needed to ensure that the best applications were chosen before the semester began to avoid confusion, which could be caused by introducing new apps during the course.

The process of incorporating the use of iPads involved choosing a set of apps offered through iTunes that would allow for an easy transition of course materials into an electronic format. On the first day of lab, students met to discuss the syllabus and obtain a list of apps that would be required for the semester. To help others interested in incorporating the iPad into the laboratory environment and to promote a paperless experience, we recommend the following apps:

- Blackboard Mobile Learn: This free app allows students to access the course Blackboard site for our university. On the course Blackboard site, all relevant handouts for the lab are posted and are easily accessed (http://www.blackboard.com/resources/mobile/mobile_learn_splash/desktop/portal-nonsprint.html#ipad)
- UPAD: Because of its ability to annotate and move Acrobat Adobe PDF files, this app was chosen to replace a paper notebook that would normally be used in the lab. This application is divided into three sections: DrawingPAD, where one can keep annotated or typed notes, BookPAD, where one can annotate and transfer PDF files, and PhotoPAD, where one can store and label photos. Files can easily be moved between these three sections and Dropbox. (<http://www.pockeysoft.com/>)
- Dropbox: This free app is used to create a folder where students place their completed assignments. Dropbox was used based on experience of the instructor and because this app is widely utilized by many users. Similar apps such as SugarSync and Google Drive also exist for such purposes. (<https://www.dropbox.com/features>).
- CloudOn: This free app allows students to utilize the Microsoft Office formats that most are currently familiar with, while being able to link files directly to a Dropbox account. (<http://site.cloudon.com/product/>)
- Chemist: The app creates a virtual lab that allows for lab simulations. This app was used by our students to create a virtual lab experiment to share with high school students. (<http://thixlab.com/chemist.html>)
- Vernier Graphical Analysis: This app is used in conjunction with the LabQuest 2 for the collection of data and its importation to the iPad for further graphical analysis (Vernier International, Sarasota, FL). LabQuest 2 interfaces with a number of probes and sensors for such measurements as pH, voltage and conductivity. (<http://www.vernier.com/products/software/ga-ipad/>)

Experimental Procedures

Prior to the beginning of the laboratory course, all experimental procedures were created and evaluated by university faculty members for demonstrating principles of general chemistry for first-year college students. The information on lab procedures for each experiment was posted on the university's Blackboard website for the course, and made accessible to students. Normally,

students would print the experiments and write the laboratory procedures into a paper notebook. Students were required to organize the lab notes into sections: the purpose, procedure, data and conclusions. The purpose and procedure sections were prepared prior to the beginning of the lab period.

This year, one section of 20 honors students utilized iPads exclusively. The workflow for using the iPads in the laboratory class is described in Figure 1. Students downloaded the experimental procedure from Blackboard and transferred the file to BookPAD within the UPAD application. From there, students annotated or made notes on the PDF file, which they then used to write the purpose and procedure in the electronic notebook before the start of the lab experiment. All general chemistry students are required to write the purpose and procedure in lab notebooks prior to the start of lab, this same rule applied to the Honors students using the iPads.

The Electronic Notebook in the Laboratory

In order to safely use the iPad in the laboratory environment where water and other chemicals could damage them, all students were given large Ziploc bags as seen in Figure 1. Every iPad was placed in the Ziploc bag during the lab period to ensure that the iPad was not contaminated or ruined by chemicals. iPads are fully functional while in the clear plastic bag. The iPad is removed temporarily to use the camera to document the lab set-up or record an image.

In place of the traditional paper lab notebook, the DrawingPAD feature of UPAD was employed. In DrawingPAD, students used a screen in which they could handwrite information using a stylus or type information using the iPad's keyboard. The DrawingPAD feature allowed handwriting that was detailed and sharp (Figure 2). UPAD also includes a PhotoPAD, which allowed students to capture pictures throughout the experiment and import them directly into their electronic notebook (Figure 4).

Before students left the lab, they were required to obtain a signature from the Teacher's Assistant or Instructor to signify a completed data report. They were then required to move the pages from the



Figure 1. The use of plastic bags to protect iPads from chemicals.

Mass of copper	1.116	g
Mass of crucible + lid	34.999	g
Mass after 1st firing	34.438	g
Mass after 2nd firing	34.491	g
1st Firing - and Firing	0.053	g
Mass after 3rd firing	34.454	g
and firing - 3rd firing	0.037	g
Mass after 4th firing	34.437	g
3rd firing - 4th firing	0.017	g
Mass of product after firing	1.438	g
Mass of Sulfur in product	0.322	g

Cu = 63.55 g/mol
S = 32.07 g/mol

Initial Conclusion: Using the law of conservation of mass, we calculated the empirical formula of the product in reaction of Copper and Sulfur to form Copper sulfide to be Cu_2S , while the expected ratio (Cu:S) was 2:1.

Figure 2. Example of Student Notebook using iPad

electronic notebook into BookPAD where they had created designated folders for each lab. Moving the file to BookPAD creates a PDF file and therefore, information could not be removed from the electronic notebook or changed without obvious alteration. Therefore, at the completion of the lab, the student had a folder within BookPAD that contained the experimental procedure and the pages from their lab notebook.

Final Reports - Electronic Submission and Grading

Before the next week lab, all students are required to complete a report sheet that allows them to submit their analyzed results and overall conclusion on a single page. Using the iPad, the Honors students would download the report sheet from Blackboard into BookPad, where they would use the stylus or text to fill out the report sheet (Figure 4). Occasionally students would also utilize

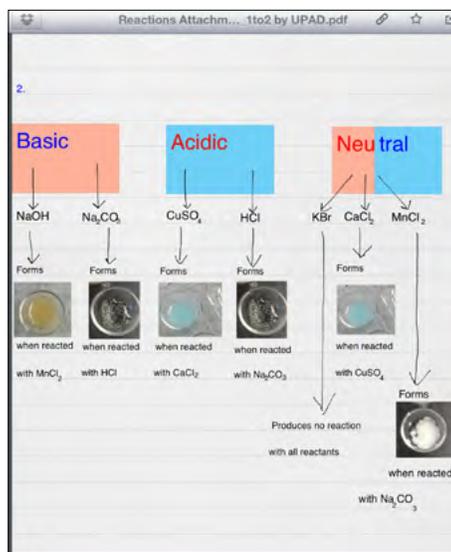


Figure 3. Example of Student Notebook with Photos

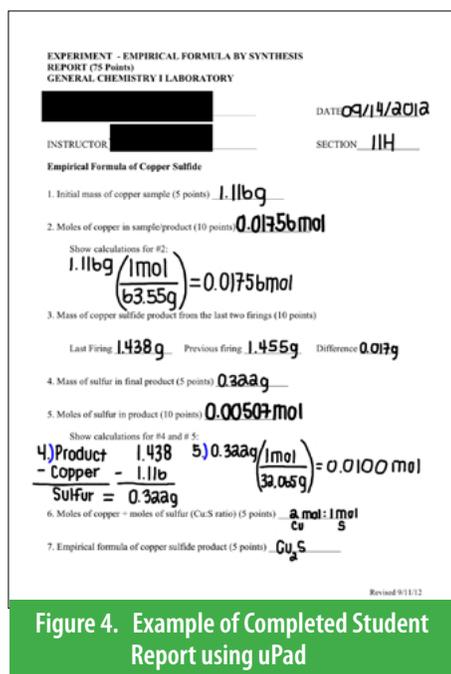


Figure 4. Example of Completed Student Report using uPAD

CloudOn, an application that allowed students to create graphs and tables for analysis to attach to the final report sheet. This application was extremely useful as it produced documents similar to those created by Microsoft Office, a software suite that most students already know how to use.

Once the lab report sheet was completed, students transferred the report to Dropbox as a PDF file into a shared folder created in advance by the instructor for each student. This allowed only the student who wrote the report and the instructor to access the documents. All reports had to be turned in within one week after the completion of the lab. Papers turned in early were not graded until after the due date so the students could modify any files before final submission. Any extra files in the shared drop box that were not turned in as part of the final lab were removed from the folder by the due date. Therefore the folder only contained final finished reports.

For the purpose of grading, the reports that were located in Dropbox were transferred to UPAD

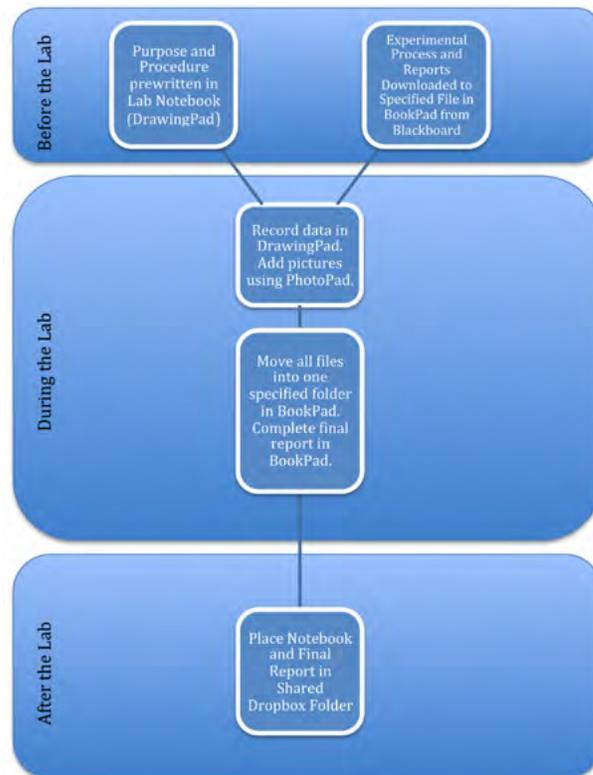


Figure 5. Overview of Student Process for Laboratory Documentation

shared Dropbox folder, overriding the previous version. Students checked back at a later date to view the graded version of their lab reports.

Discussion

Instructors interested in presenting a paperless lab experience using an iPad or related mobile device must realize that considerable effort is needed before the course begins to evaluate potential apps and design the overall workflow. David Rath (2012) noted that "the iPad is only as good as the applications and tools loaded onto it," and it should be added that the use of the iPad and its apps are only as good as their implementation by users. To help students, it is important to describe the procedures for using and maintaining an electronic notebook, and it is helpful to expand upon specific tasks with explanatory pictures. Overall, in our course, preparing the paperless lab procedures took more time than is involved in getting ready for a traditional course.

We found that students, despite being the Millennial Generation comfortable with the use of modern technology, are likely to encounter a steep learning curve during the first few lab classes. The majority of students were enthusiastic about using iPads in the lab and in exploring a paperless environment. Since many of our students have an interest in forensic science, they were particularly fascinated by the paper by Samms, W.C. & Mozayani, A. (2012) on the design and implementation of a paperless forensic laboratory. Nevertheless, students encountered difficulties that arose as a result of using this totally digital approach. During the first week of lab, students were actually quite frustrated with the small nuances of the apps that kept them from swiftly moving along. For example, many students found it frustrating that they could not have two windows open simultaneously. In order to look back at a previous document or look up a literature value, they would close one application to access the other. One particular student stated that, "the inability to look at two pages simultaneously/compare quickly between data separated over several pages, hinders my work." A second student felt similar frustration and reported, "I really am not a fan of the constant flipping back and forth between Drawpad

and Bookpad or between documents to complete lab reports. I wish you could have two up at the same time." Once students became more familiar with the iPad and its operating system, they realized they could easily flip between applications by viewing open apps rather than completely closing one to enter another.

Also, students were not comfortable with using the device for writing during the first few weeks of the iPad implementation. After a couple attempts at recording notes, students learned that zooming in allowed for more precise writing with a stylus, but some felt that, "the limited space for writing requires a lot of zooming in and zooming out, making it hard to see what you are doing overall, slowing work." Early feedback from students revealed comments such as, "I don't like how difficult it is to write. I got used to it after a while and a lot of practice, but at the beginning, it was difficult to write without my palm touching the screen." These difficulties were soon overcome with experience.

As instructors, we encountered initial difficulties when grading the first round of final lab reports. The student reports were opened in Dropbox, and then moved to UPAD for annotations. The goal was to correct the electronic copies and then transfer them back to Dropbox and overwrite the existing uncorrected version. The graded report was renamed when returned to UPAD. Therefore, to overwrite the previous file as desired and end up with a single corrected version in the folder, part of the file new name had to be deleted.

There was also an issue in UPAD when transferring to Dropbox as all shared folders were subfolders under "Honors Labs" and these were not recognized by UPAD. To remedy this, all shared student folders were moved back to the higher level folder. It is important to note that proper naming of files and folders is very important, as much of the name is cut off when viewing files name prior to opening.

An early assessment survey to evaluate the usefulness of iPads and the quality of the paperless lab experience was distributed approximately 10 weeks into the first semester. This included a short survey of questions requesting written responses from students answering what they liked the most and least about the iPad integration to date, their previous experience with technology and their thoughts on its use from a global perspective. Despite encountering difficulties early on as a class, the feedback on the iPad integration in the laboratory was positive with early feedback comments:

- "I believe it has enhanced the lab experience. It forces you to use technology whether you really want to or not, and it makes you learn about different types of technologies on the iPad. Yes, it may be difficult to adjust at first, but as soon as you realize the value of this technology, you learn how great it really is." -L.E.
- "Using the iPads in lab has been a positive experience. It is a stepping stone to a paperless future. I also like it because it is easy to organize. I can separate all of my documents into their appropriate folders and I can color code and make helpful visuals." -A.G.
- "I like that there are so many tools at my fingertips as far as writing utensils/ colors/highlighters, apps such as timers, periodic table, and overall web access. Undo and redo buttons make alterations quick and easy. Overall, I really appreciate exposure to the device, as I believe being versed in its use as a tool will make me more competitive in the labor force." -J.Z.
- "I love being able to take screenshots and pictures of lab tables and just copy it right into my notebook, as well as type things. It helps make my notebook look so neat and organized." -L.E.
- "It certainly saves so much paper! In the long run, it may be cheaper for everyone with the lack of paper used. I see how much paper my roommates use for their lab notebooks/reports...it's insane!"
- "I love this iPad. :) Thank you!"

General Chemistry, being a two semester course, will complete further assessment at the end of the course. Future questions are being developed

using a Likert scale survey with the intent to analyze students' satisfaction and perceived achievement with the integration of the technology. These surveys will address the lecture and the laboratory portion of the class and, if applicable, will include normalized achievement data in comparison to prior sections of the course. Any data obtained from completion of the surveys will be described in future articles.

Conclusions

As we reviewed our experience to date, we wanted to convey two positive messages: First, the paperless approach afforded by the use of iPads in the laboratory lessened the environmental impact of conducting labs. We estimate that more than 120 pages of paper per student were saved over the course of one semester of 11 lab experiments. In addition, the paperless experience exposed students to digital laboratory techniques that are increasingly employed in academia and industry (Giles, J., 2012; Rubacha, M., Rattan, A.K. & Hosselet, S.C., 2011; Samms, W.C. & Mozayani, A., 2012).

Second, the iPad had considerable advantages over laptop computers in the laboratory. The iPad is less costly than a laptop and, in contrast to personal computer software, useful apps for the iPad are widely available, easy to use and generally inexpensive. A student can easily use apps to write and draw on the iPad and can easily incorporate that material into an e-notebook. The iPad has a camera that readily allows for more comprehensive documentation of laboratory observations. The iPad is more mobile and easier to protect from simple laboratory accidents (as noted, placing the iPad in a Ziploc bag did not reduce functionality but protected the iPad from potential spills). It is clear that iPads and related mobile devices have enormous potential as useful laboratory tools (Giles, J., 2012; Powell, K., 2012).

We envision the integration of iPads as a technology that will be introduced into many facets of learning. In addition to our experience with the paperless laboratory, the iPad is currently utilized in the lecture portion of the General Chemistry course, allowing an increased level of student engagement. Using the iPads, students responded to questions asked by the instructor during class and answers were monitored interactively. Students used the iPad in lecture to open and annotate PDF documents containing the course slides and practice problems (Schwartz, 2011). Other faculty are planning to integrate the use of iPads into courses in the fields of graphic design, history and math. Introduction of any new technology can add layers of difficulty for students and instructors, which can easily become a distraction that adversely affects the learning experience. However, as we are well aware, our students and society in general have high expectations for the use of technology to advance learning in our educational system. Therefore, it is necessary that we explore the possibilities and access their true value in the learning process. Our experience to date has been overwhelmingly positive and we hope others will gain from our efforts to introduce iPads into laboratory science classes.

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