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Combining Cloud Networks and Course Management Systems for Enhanced Analysis in Teaching Laboratories

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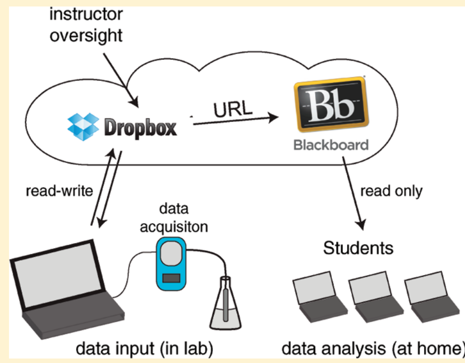
Ⓢ *Supporting Information*

ABSTRACT: A cloud network system is combined with standard computing applications and a course management system to provide a robust method for sharing data among students. This system provides a unique method to improve data analysis by easily increasing the amount of sampled data available for analysis. The data can be shared within one course as well as used in interdisciplinary environments. Student accessibility is improved over other data sharing methods with the benefit of minimal oversight required by the instructor. The networked system is ideal for large enrollment and research-based laboratory courses. Methods for implementation in research labs are also described.



KEYWORDS: *First-Year Undergraduate/General, Graduate Education/Research, High School/Introductory Chemistry, Environmental Chemistry, Laboratory Instruction, Computer-Based Learning, Laboratory Computing/Interfacing, Laboratory Management*

Student enrollment continues to grow in science courses, oftentimes commensurate with increased faculty teaching loads. The disadvantages are numerous, but there is one great advantage to large lab courses: more data! By using online data sharing, students can share data in real-time, yielding immediate improvements in comparison and analysis. Students in laboratory classes are often treated as autonomous experimenters, using their own data as the sole source for analysis and discussion. There is significant power in data analysis when the entire enrollment of a course can easily share data with minimal instructor (or student) input. Lab partners or small groups may be employed to share data, but this often becomes unwieldy to share data among a section of 20+ students, let alone a whole laboratory course of 100−1000+ students. Difficulties can arise in the sharing of data, as some students complete experiments before others and do not wish to wait for their peers to finish. Furthermore, experimental errors may need to be statistically removed by the instructor before allowing students to use the data for their own analysis. Other options include having instructors or teaching assistants (TAs) manually input data into a spreadsheet and e-mailing this to students, but this becomes laborious and error prone. There are clear advantages, however, to sharing data among students in a course. Multiple data sets decrease error, improve statistical analysis, and in some special cases, allow for students to complete a dry lab if it is not feasible for a student to attend lab. There are also advantages when two or more courses are intertwined and data can be shared openly among those courses. This article describes the advantages, positive outcomes, challenges, and potential uses of sharing data in real-time during a general chemistry laboratory course using cloud-computing networks. This same technology can be used in research labs for sharing group information.

The current generation of students has been hailed as the "plugged in" generation,[1] always being online. It is reported in the literature that students have limited knowledge in working with common scientific computing methods such as Excel formulas, graphs, and databases,[2,3] though they have strong familiarity with basic word processing and accessing social media. On the basis of this dichotomy of computing skill, requiring students to create separate accounts, remember passwords, and following a myriad of steps to access and process data can be a challenge. To alleviate the technical challenges, three integrated applications are used for students to view and work with data: (a) Blackboard, a course-management system;[4] (b) Excel for plotting and data analysis; and (c) Dropbox,[5] a cloud-network storage system. This system simplifies the technical requirements on the user-end and removes the extra steps toward data accessibility.

■ IMPLEMENTING A CLOUD NETWORK WITH A COURSE MANAGEMENT SYSTEM

The cloud networks described here differ from campus-wide storage systems, such as storage-area networks (SANs), that require IT-implementation, student-user authentication, and significant up-front costs. Several flavors of cloud network storage exist, and arguably, the most common application,

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Dropbox,[6] is used. Dropbox exists as both a Web-based and desktop application and is free for the first 2 GB of storage, which more than meets the demands for this course. Desktop applications currently exist for Windows, OSX, iOS, Linux, and several mobile devices. The Web application is available on all operating systems and common browsers. In all cases, the application provides fully synced file access to any device connected to the Internet. Dropbox requires a user account for access, linked to an e-mail address. When the Dropbox application is installed on a computer, a specific Dropbox folder is added per user account, typically inside the default documents folder (e.g., My Documents). Files and folders added to the Dropbox folder will be automatically synced to the cloud as long as an Internet connection is present. The data are then immediately accessible to any other computer running the Dropbox application or users who have access to the Dropbox Web site (Figure 1). Dropbox also acts as a backup device and maintains a limited file history, allowing access to prior versions of files in case of accidental or unintended file changes.

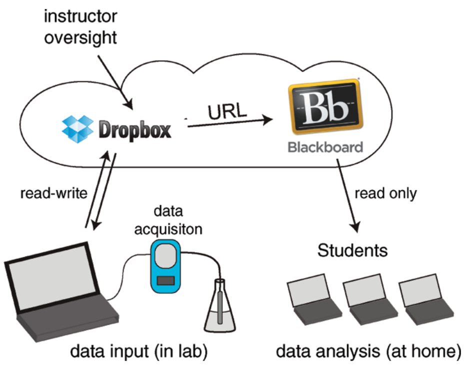

Figure 1. Pictorial representation of implementation of a cloud network.

In the case of teaching labs, data are entered in the lab on a single computer that is synced to a public folder in the cloud. Dropbox does not require user accounts for others to access public files or folders, making student input rather passive. To make data files and folders accessible to students in class, a specific folder's static URL is made available via Blackboard, the chosen course-management system on this campus. Integrating the URL within Blackboard has the other advantage of student familiarity as many faculty use Blackboard or similar systems as part of their course structure. Because files have read-only access to students via the URL link (i.e., download-only), they do not have the ability to accidentally modify other students' data after they leave the lab, a potential problem with other technologies such as wikis. Additionally, individual files can also be password protected, locking certain aspects such as formula cells in Excel, thus, limiting unintended student errors. The ability to make any folder shareable was added in a recent stable version of Dropbox, 1.0.20.

■ STUDENTS LABORATORY

Logistics

The general chemistry lab enrollment is typically 300−325 students with 14 sections ranging from 22−30 students per section led by one faculty member and a team of teaching assistants. Laboratories are taught in two different rooms, sometimes concurrently. Each room is equipped with one laptop computer. The laptops in the laboratories have access to the campus wireless network and are online for immediate data syncing. To prevent file conflicts from concurrent sections, each section is assigned a folder for saving data. All students are automatically enrolled in the Blackboard sites for the course in which they are registered, providing seamless integration of the Dropbox URL with Blackboard. The course instructor employs one account for Dropbox, the chosen cloud networking service.

Power of Multiple Data Sets

Several articles in this *Journal* cite the advantages of having students conduct research or inquiry-driven experiments throughout a laboratory course.[7−11] To obtain useful data for analysis, however, large data sets must be made available to the students and the instructor. Online data storage allows immediate accessibility to the data without concern of retrieving data from students and large enrollment courses can quickly acquire numerous data points for subsequent analyses. Though the validity of the data may be in question with novice experimenters, a test for outliers can be implemented[12] automatically using an Excel macro and made available to the class or just the instructor as needed (see Supporting Information). An added benefit arises when students, for one reason or another, cannot attend a certain lab. There is no substitute for hands-on lab work, but when data are posted and accessible, students can complete a dry lab if appropriate, performing the analysis with actual student-acquired data rather than a set contrived by the instructor or themselves. Some specific implementations of this technology are listed below.

Soil and Water Analysis

An introductory lab was designed for students to study soil chemistry at four different forest plots, each with primary and secondary woodlots, totaling eight unique sets of data. Students measured moisture content, organic content, and pH of the soil and gathered one data point for each of the measurements. As students completed the chemical analyses in the lab, the data were immediately input onto a Dropbox-synced Excel spreadsheet in the lab. After the lab, students accessed the combined section-wide data via the Blackboard course link and were instructed on the use of simple spreadsheet functions to assist in data analysis and draw data-based conclusions. Although students only gathered one data point each, they were able to complete a simple statistical analysis based on the many data points acquired by their peers during the course of the laboratory experiment, up to 42 per geographic site. More experimental information is given in the Supporting Information. Because this was an introductory lab, some of the student data were flawed and the instructor was able to easily modify or remove data as needed prior to the analysis to prevent confusion.

In a related lab on water-quality analysis, students entered titration volumes and absorbance data directly into Excel, which autocalculated values such as concentration (molarity and ppm) as well as linear regressions. Although students were required to show *how* the data were calculated for their final reports, they could use simple spreadsheet functions to gather statistics and create graphs for large data sets (Figure 2). Certain cells were locked in the spreadsheet so formulas would not be accidentally manipulated or displayed. The instructor accessibility for editing was particularly helpful when some students accidentally reported negative ion concentrations!

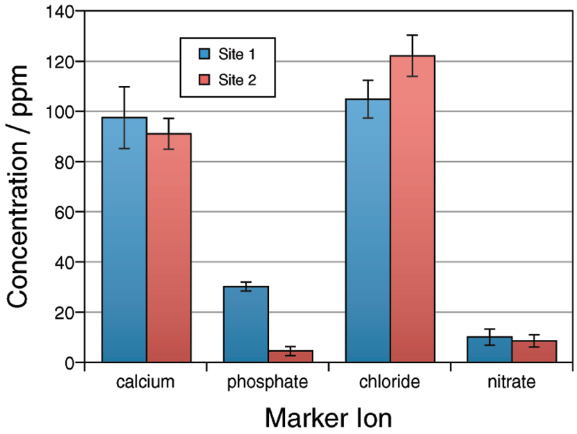

Figure 2. Column chart assembled from aggregated student data, n = 22–48, depending on the lab day.

Dye Spectra

Another implementation has involved accessing and processing data from portable data acquisition devices, namely, the Vernier LabQuest.[13] Other articles in this *Journal* have reviewed the LabQuest and its functions, one of which is the ability to download data directly from the LabQuest to a computer.[14−16] Although the process to download the data is relatively simple, students have been challenged with how to get the data from the computer in the teaching lab to their own computers for subsequent analysis. Not all students possess flash drives and sending the files via e-mail is time-consuming. Students were tasked to acquire a visible absorption spectrum of an assigned metal salt solution, report λ_{max}, include the absorption spectrum in their reports, and compare the spectra to those obtained by their peers. In the implementation of cloud-network storage, students downloaded data from the LabQuest and exported it to a designated Dropbox-synced folder. They were then able to access the data via Dropbox URL through Blackboard. As students analyzed the data, instructors could immediately access it and assist with any problems or questions the student may have. One case specifically involved improper orientation of the cuvette, resulting in flawed data, though immediate instructor intervention prevented the class from trying to analyze the data.

Data Sharing between Sections, Courses, and Years

The cloud storage has been used among multiple sections and between courses. In the latter case, data from the above-described soil analysis lab was subsequently shared with the general biology laboratory so students could study plant growth in different soil conditions. This implementation allowed data sharing between disciplines, yielding more time for mastery and visualization in each specific discipline. This also resulted in students having a scientific collaborative experience, a known catalyst for improved scientific understanding[17] and attitude.[10,18,19] As Blackboard is available to all courses at this college, this strategy could be easily implemented across campus. Because the data are now more accessible, they could also be used in annual studies of water and soil chemistry at given sites.

■ RESEARCH LABORATORY GROUPS

Cloud networks also integrate well in research labs given the constant rate of student turnover. Not so long ago, data were kept together with procedural notes in lab notebooks, taping NMR spectra and GC printouts in the pages. As computers entered labs, there tended to be one or more "lab computers" that belonged to the principal investigator (PI). Any acquired data were on those computers and stayed there long after the student graduated or left the group. Currently, many students have their own laptop computers, which are an advantage, as the PI does not need to constantly upgrade or buy new computers. The potential downside is that research information stays with that student, which limits the PI's access to the data.

Cloud computing has solved this problem by securely storing data so it can be made accessible to students as long as required by the PI. The implementation of Dropbox allows the PI to share specific folders with students, for example, a folder for each research project, person, or set of journal articles. Data can also be added when students are using instrumentation or computers not directly connected to a cloud network account (e.g., data from an NMR or SEM) as they can upload files via the Web interface. As mentioned earlier, the addition of automatic backup and limited data restore is also a clear advantage in this application. As students graduate or leave the group, their account can be unlinked, thus, limiting access. If security is an issue, a clear downside to this is that a local version of the data still remains on their personal machine, so server-only implementations may be more advantageous (where no data are saved on the local computer). Another requirement of this implementation is that the student possesses his or her own Dropbox account. As further evidence for success in the research labs, a recent article in this *Journal* by Bennett and Pence describes the use of GoogleDocs to both (a) manage a research project and (b) develop the project into a laboratory experiment.[20] There is a limitation, however, regarding the types of files that can be viewed though GoogleDocs: documents, spreadsheets, presentations, and drawings. Although beyond the scope of this article, cloud networks also have the potential to be integrated with online e-notebook systems, allowing PI-access to student data at all times. In addition, the National Science Foundation (NSF) recently implemented a data management plan[21] for all funded research and cloud networks can provide a potential forum for collaboration and data sharing to meet this requirement.

■ STUDENT FEEDBACK AND EVALUATION

Students and TAs in the general chemistry lab were asked to complete a postsemester course survey. Nearly 52% of the enrolled students and 93% of graduate TAs responded. Student feedback indicated that only a minority of students have Google accounts and even fewer owned a smartphone. The lack of new technology in this student population suggested that implementing passive data aggregation and sharing is advantageous. The method described here provided a larger umbrella for catching all students, regardless of the type of phone, e-mail, or technology system they use. As one student commented:

> *I'm not usually very good with using technology like Dropbox, however, I found that it made my labs much smoother to complete. Being able to see all the data in one place allowed me to analyze it and understand trends with ease.*

Due to variations in student and TA populations as well as changing laboratory experiments, it cannot be stated that student scores improved using this technology, but student perceptions suggested their learning improved. Students also recognized the real-world component of sharing data among peers and external groups (other courses):

I feel that it has been good to view large amounts of data because it is more similar to the data that we will be sorting through during our later careers, and it has allowed me to observe patterns within a mass of numbers.

A summary of survey results for combined categories "agree" or "strongly agree" are listed in Table 1. The majority of remaining responses were "neither agree or disagree", with very few responses given as "disagree" or "strongly disagree". The results indicate that students believe their understanding of concepts improved in lab, but TAs felt that the cloud system did not improve student learning. This discontinuity will be the subject of further study. TAs did, however, indicate that Dropbox eased the process of assisting students, likely due to the easy retrieval of data if students came to office hours without their own data.

Table 1. Survey Results from Students and Teaching Assistants

Survey Question	Respondents listing "Agree" or "Strongly Agree" (% of respondents)
Undergraduate Students[a]	
Using Dropbox for data sharing was simple and enjoyable.	81.4
Analyzing large data sets helped you to reach a conclusion.	85.2
Analyzing large data sets offered a broader view of the experimental variables.	91.6
Analyzing large data sets has helped you in other courses to date.	60.2
Storing the data online allowed you to seek assistance from instructors (including TAs) more readily.	58.7
Teaching Assistants	
As a teaching assistant, Dropbox makes it easier for me to assist students with data analysis.	84.6
Students were able to easily share data amongst one another using Dropbox.	76.9
Students are able to better understand underlying chemical concepts when Dropbox is used to complement the lab.	46.2
Dropbox allowed students to have a broader view of how their piece of data fit into an experiment.	61.6

[a]Most students were first-year college students.

■ LIMITATIONS

A major drawback to an application like Dropbox is the lack of simultaneous user input. As data are actually stored locally on the computer *then* synced to the cloud upon saving, simultaneous versions cannot be opened and saved without causing file conflicts. These situations can be remedied manually, but in situations when this might frequently occur, GoogleDocs[22] or wikis may be more advantageous as these programs function as server-side applications. One disadvantage to an application like GoogleDocs, however, is the need for all users to have a Google account, an unrealistic requirement for large enrollment courses. On this campus, for example, only 43% of survey respondents enrolled in the general chemistry lab had a Google account. This may or may not be a problem for small courses or institutions that already implement Google Docs for file sharing. Surprisingly, having only one computer available for data input in each lab was not a significant limitation. Over 81% of students believed there was not a significant waiting time to enter data.

A course management system such as Blackboard is not required to use data syncing as it is described in this article, but it does help with URL centralization. It would also be possible to simply e-mail students the Dropbox URL or put the URL on an instructor's Web site, but the ease and prevalent use of course management systems simplifies the process.

■ CONCLUSION

Technology should never get in the way of education. Given that mantra, adding in more technology "steps" to solve a problem or analyze data can serve as destructive interference toward learning, getting in the way of the true educational goal. Cloud network sync-storage systems such as Dropbox and GoogleDocs allow for the virtually limitless acquisition, sharing, and editing of information without the need for a campus-wide SAN. Students benefit from not only improved data analysis, but the realization that the class as a whole must rely on one another to accomplish the task (goal interdependence).[23] By connecting in-lab data to the cloud, information can be updated in real-time with both transparency for students and simple modification by instructors. The only interaction required is that of the instructor for initial setup, in addition to optional items such as file merging or data modification. The syncing system employed in the labs is both seamless and invisible to the student-user, resulting in simpler data collection and improved student analysis.

■ ASSOCIATED CONTENT

Supporting Information

Excel files that incorporate the use of statistics-based removal of data outliers and data from forest soil analysis; student handout for the soil lab and a GIS image of data from field site of the soil lab; complete survey results from students and TAs; and a step-by-step setup and operational guide. This material is available via the Internet at http://pubs.acs.org.

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