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Technology Report

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Bring Your Own Device: A Digital Notebook for Undergraduate Biochemistry Laboratory Using a Free, Cross-Platform Application

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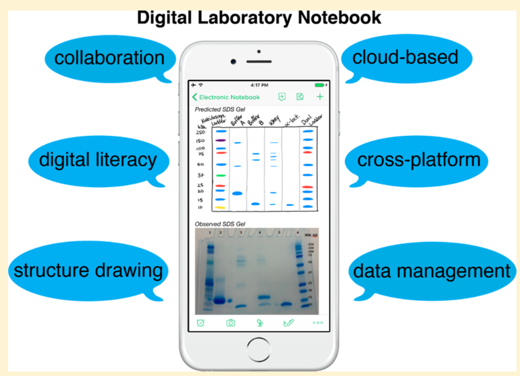
Ⓢ *Supporting Information*

ABSTRACT: The majority of undergraduates own a smartphone, yet fewer than half view it as a valuable learning technology. Consequently, a digital laboratory notebook (DLN) was developed for an upper-division undergraduate biochemistry laboratory course using the free mobile application Evernote. The cloud-based DLN capitalized on the unique features of smartphones (i.e., photo uploading, audio capture, dictation) and could also be accessed from any Internet-connected device (i.e., tablet, laptop, desktop). This cross-platform flexibility enabled a "Bring Your Own Device" philosophy in the course, leveraging the educational power of students' personal devices. The DLN served as a secure data management system, where any file could be attached, edited, and analyzed. The DLN also accommodated freehand drawing. A postsemester survey indicated that the cloud connectivity of the DLN facilitated greater collaboration between students and enhanced the quality of their communication with the instructor compared with traditional paper notebooks. Given the option, 70% of students reported that they would choose a DLN over a paper notebook in the future. By using a DLN, students further cultivated their digital and chemical information literacy, which is important to develop as the healthcare and industrial sectors continue to digitize their workflows.



KEYWORDS: *General Public, Upper-Division Undergraduate, Biochemistry, Chemoinformatics, Internet/Web-Based Learning, Laboratory Computing/Interfacing*

■ INTRODUCTION

Smartphones are ubiquitous, owned by 85% of undergraduates nationwide.[1] They can deepen student engagement in chemistry lecture[2−7] and laboratory[8−10] as well as aid universal access for the visually impaired.[11] However, only 18% of instructors create activities that utilize smartphones, and fewer than half of undergraduates (45%) view smartphones as important to their academic success.[12] As the healthcare[13] and industrial sectors[14,15] digitize their record keeping, undergraduates must cultivate digital literacy. The American Library Association defines digital literacy as "the ability to use information and communication technologies to find, evaluate, create and communicate information, requiring both cognitive and technical skills."[16] The American Chemical Society (ACS) actively promotes digital literacy through the work of the Division of Chemical Information.[17] The ACS Committee on Professional Training (CPT) recognizes digital literacy as a key element in undergraduate education, calling for instruction "in data management and archiving, record keeping (electronic and otherwise)...this includes notebooks, data storage, and information management."[18]

This technology report describes a digital laboratory notebook (DLN) for undergraduates, designed using the smartphone application Evernote.[19] Unlike DLNs designed primarily for mobile devices such as Notability,[20] Evernote is not constrained to a single platform (Supporting Information 1). It can be accessed from any Internet-enabled device (e.g., mobile, desktop, or instrument with web browser), facilitating data entry and management. Evernote employs a familiar word-processor style interface, similar to DLNs developed using Wikis[21] or blogs.[22,23] Most compelling, though, is that Evernote exemplifies digital hygiene by directly inserting data files (in their native format) into a note, pairing those files with the corresponding experiment. As a result, the user is offered an easily interpretable visual catalog (Supporting Information 2). This is in contrast to directory interfaces like GoogleDrive[24,25] and Dropbox,[26] which require an undergraduate to manually pair data files with an experiment, a skill that can prove challenging.[27] Furthermore, commercial DLNs[28,29] are often developed for highly specific workflows (e.g., high-throughput screening, organic synthesis, genomics) and lack the flexibility to be deployed across a diverse undergraduate curriculum. Evernote overcomes this limitation through user-generated templates (Supporting Information 3). Finally, Evernote features a built-in chat function, rare in most DLNs, to facilitate student−student and student−faculty communication. Evernote is not without limitations. A free account limits activating the mobile app to two devices. This can be

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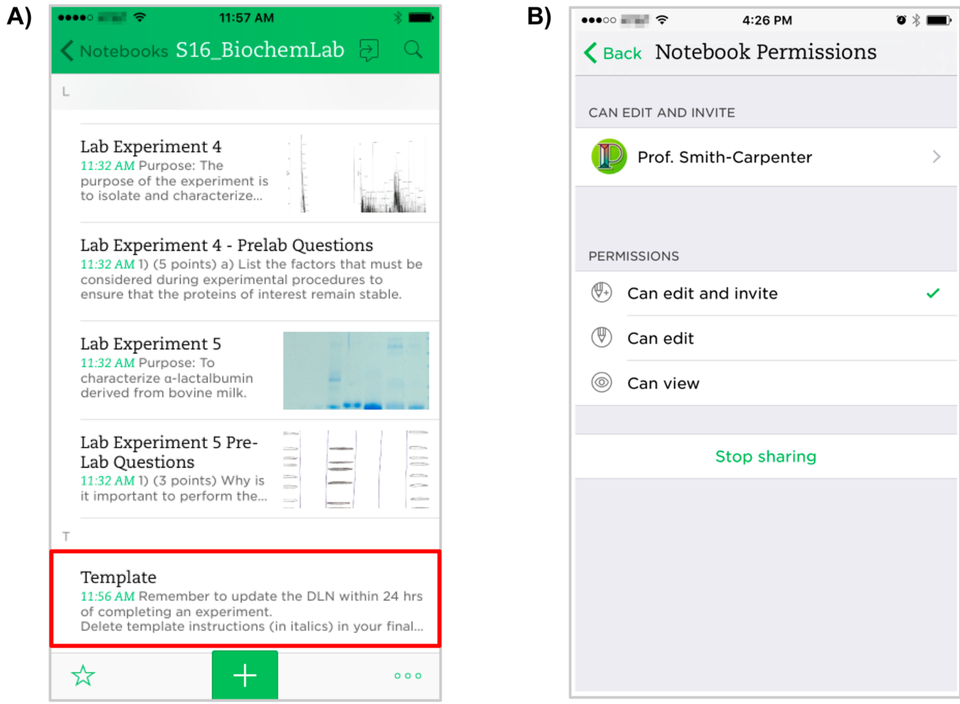

Figure 1. Screenshots of a DLN on a smartphone. (A) Student's notebook containing individual notes. The template note (highlighted in red) can be viewed in the Supporting Information. (B) Notebook permissions can be changed by the instructor to set "due dates" for students.

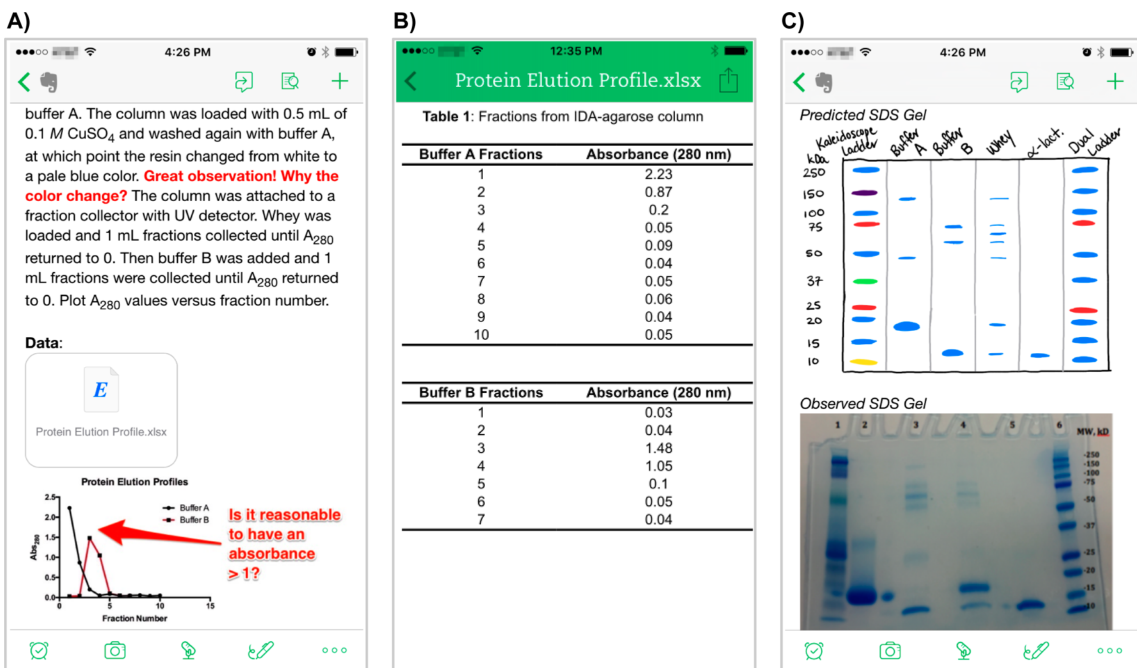

Figure 2. Screenshots of a student's DLN shown on a smartphone. The complete DLN entry is available in the Supporting Information. (A) Excerpt illustrating the procedure for affinity chromatography of milk whey and the DLN's data management system (Excel and JPEG attachments). Red font indicates instructor's feedback. (B) Preview of the Excel attachment. (C) Excerpt exemplifying the DLN's freehand drawing capability (top) and photo capture ability (bottom).

circumvented using the web version, which does not count devices. Additionally, multiple users cannot simultaneously edit a shared file within Evernote. Despite these caveats and comparing the price structure of Evernote to other DLNs (Supporting Information 1), it offers a compelling platform for constructing an undergraduate DLN.[30]

DIGITIAL LABORATORY NOTEBOOK

The Evernote Environment

A basic Evernote account is free and sufficient for students; tiered membership can be purchased for a nominal monthly fee ($3–6 per month) and is recommended for instructors.[31,32] Evernote is organized as a series of notebooks populated with

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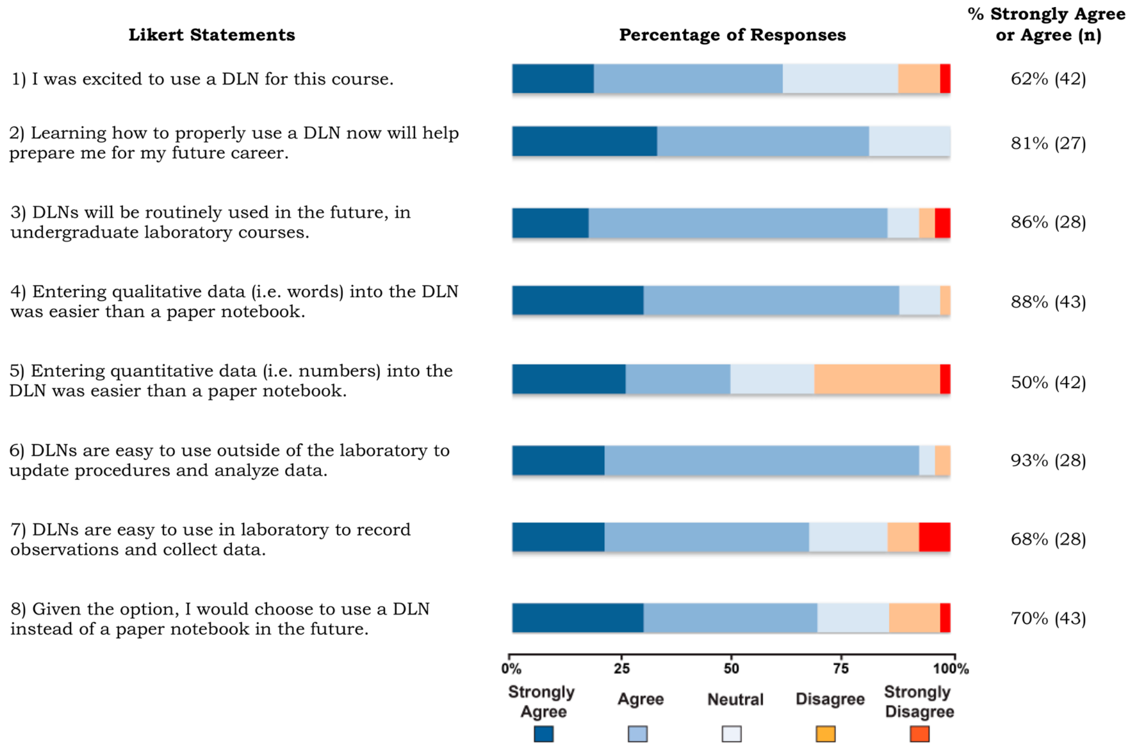

Figure 3. Students' responses to the statements at the left, shown on a Likert scale: strongly agree (dark blue), agree (light blue), neutral (gray), disagree (orange), strongly disagree (red). The percentage of students who responded "strongly agree" or "agree" to each statement is shown; the number of responses is indicated in parentheses.

individual notes (Figure 1A). The instructor creates and shares notebooks with students (Supporting Information 4). In this way, the instructor retains ownership over the notebook and can control when students share, edit, or view its contents (Figure 1B). The instructor can view any student's DLN in real time from a mobile device, desktop computer, or web browser.

Because Evernote runs on any Internet-enabled device (e.g., smartphone, tablet, or laptop) the course adopted a "Bring Your Own Device" (BYOD) philosophy regarding the DLN.[33] BYOD frees a department from purchasing expensive devices that quickly become obsolete. Additionally, students were more comfortable working with their own devices. BYOD helped students to recognize that no single device is a "magic bullet" and that a skill of digital literacy is to discern the most appropriate device for a specific task. For example, students used their small, portable smartphones to capture data at shared instruments yet gravitated toward their larger laptop screens to analyze data. Because the DLN was cloud-based, students could easily switch between two different devices to complete their work.

DLN in Biochemistry Laboratory

The DLN has been employed three times in an upper-division undergraduate biochemistry laboratory course (16 students/semester) since 2015. Because Evernote was a tabula rasa, it prompted a class discussion about the key elements of an electronic notebook and the importance of metadata.[34,35] The result was a student-generated template for all DLN users in the biochemistry laboratory (Supporting Information 3). The template was divided into subsections: researchers' names, experimental objectives, materials, procedure (with observations), data, and conclusions. For each new experiment, students copied and filled out the template. Importantly, student-generated templates retained flexibility. For example, in a mushroom tyrosinase kinetics experiment,[36] students added a subsection to the template for reaction schemes. Using a chemical structure drawing application, they then generated a scheme showing the conversion of substrate to product and inserted it into the DLN (Supporting Information 5).[37−40] Many commercial DLNs lack this level of template flexibility. The Evernote DLN could easily be adapted for other courses, such as organic chemistry or general chemistry.

A representative DLN is shown in Figure 2, where a student isolated and characterized α-lactalbumin from milk.[41] The excerpt begins with affinity chromatography of milk whey (Figure 2A). The DLN eliminated unintelligible student (and instructor) handwriting. The dictation feature was also useful for keeping hands free during the lab. Notably, the DLN served as a data management system, as any file type can be attached to Evernote in its native format (e.g., Excel, PDF, NMR-FID, chromatogram). Figure 2A shows a protein elution graph (JPEG file) stored along with the raw absorbance values of the individual fractions (Excel file). On a mobile device, a single tap of the Excel attachment opened its contents (Figure 2B), and a second tap allowed it to be edited in the parent Excel application and the changes to be saved in the DLN. In this way, the DLN serves as both a secure data management system and a data storage system. Additionally, the Evernote environment teaches students to pair data files with their experiments, a critical skill of digital literacy and electronic hygiene.

Finally, DLNs are often criticized for their lack of freehand drawing.[42] Evernote added this functionality to mobile devices in 2015. Figure 2C displays a student's sketch of the predicted acrylamide gel next to the experimentally obtained gel. An advantage of using a popular platform such as Evernote is that new features are continually being added. This is in contrast to

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a commercial DLN, where one would have to pay for version upgrades.

Instructional Advantages of the DLN

The DLN offered numerous instructional advantages. Data were efficiently collected and stored compared with paper notebooks. When working on instruments with a web browser, students could upload data directly to their DLNs. This eliminated the need to carry flash drives or use a second cloud storage system. Because data files were edited and analyzed within the DLN, it doubled as a secure cloud storage system.

Digital copying and pasting replaced the literal cutting and pasting of paper notebooks. Students generated schemes and figures and inserted them into their DLNs (Figure 2A). Indeed, narrative feedback from students consistently cited the ease of collecting data with the DLN and its "paperless" quality (Supporting Information 6A,C). Students also remarked that DLNs were neater and more organized than paper notebooks, as they did not have to predict how many pages to reserve for an experiment; a digital page is infinitely scalable.

The DLN simplified consultation and assessment by the instructor. The ability to view a student's DLN enhanced the quality of instructor responses to student e-mails regarding lab. Furthermore, as Evernote premium subscribers, instructors could track changes to a student's DLN. This digital timeline provided rich insight into the student's thought process and served as a safeguard against students erasing data. Periodically, students submitted their DLNs for assessment, and their access was changed from "edit" to "view" (Figure 1B). The instructor, as the notebook's owner, retained full editing privileges. Just as students could work on the DLN from multiple devices, instructors could also assess the DLN from multiple devices and typically chose a tablet or laptop for convenience. Feedback was typed in a distinctive red font or by annotating figures using Skitch (Figure 2A, red text), a free plugin.[43] Students liked not turning in paper notebooks; instructors liked not collecting and carrying paper notebooks.

■ STUDENT ASSESSMENT

Survey Results

A postsemester survey was administered to assess students' experiences using the DLN. The survey consisted of eight statements on a Likert scale (Figure 3) and three open-ended questions (Supporting Information 6). The first three Likert statements assessed student attitudes toward DLNs. Responses indicated that most students were excited to use the DLN. Additionally, students believed the DLN will help prepare them for their future career and that DLNs will become routine in undergraduate laboratories. As healthcare, medical, and research companies continue to move toward digital platforms, cultivating digital literacy in our students is increasingly important.

Likert statements four and five investigated the student's experience entering data into the DLN. Almost 90% of the students agreed or strongly agreed that entering qualitative data was easier than with a paper notebook (Figure 3). In contrast, only 50% of students agreed or strongly agreed that quantitative data entry was easier with the DLN than with a paper notebook. This divide reflected Evernote's rudimentary tables, a reason why students were encouraged to work with Excel attachments. It may also reflect students' greater experience using their mobile devices for typing but relatively limited experience using them for numerical data entry. Consequently, many students opted to bring a laptop in addition to their smartphone for spreadsheet-intensive laboratories. Through this act, students exhibited a valuable skill of digital literacy: they discerned which computing device was most appropriate for a specific task.

Likert statements six through eight gauged the students' overall experiences using the DLN. The majority of students (68%) agreed that it was easy to collect data with the DLN. Impressively, 93% of the students agreed or strongly agreed that the DLN was easy to use outside of the laboratory. The cloud-based DLNs lowered the barrier to accessing data and increased student collaboration. Because students worked in pairs, traditional paper notebooks made data consultation difficult outside of class. This was especially challenging for the course's small but measurable cohort of commuter students. As today's students are virtually inseparable from their devices, they can always connect to their DLN. Indeed, students reported the most advantageous feature of the DLN was facilitating collaboration between lab partners (Supporting Information 6A,C). The Evernote DLN could be a transformative technology at institutions with large commuter populations. Furthermore, increased collaboration may indicate a shift toward a more cooperative learning environment.[44] Finally, given the choice, 70% of students would choose to use a DLN instead of a paper notebook in the future (Figure 3).

Improving the DLN

Student feedback aided the continual evolution of the DLN. A common student concern was exposing personal computing devices to laboratory chemicals (Supporting Information 6B). To address this concern, raised stands, external keyboards, and mice were purchased for laptops (at a cost of $30 per lab station; Supporting Information 7). As a component of digital literacy, it is important to teach students how to safely integrate electronics with chemical hygiene. Students also cited frustration with Evernote's formatting, but nearly an equal number of comments acknowledged that students needed to spend more time familiarizing themselves with the application at the start of the semester. One specific feature worthy of highlighting to students is Evernote's freehand drawing capability. This feature addresses recurring student criticisms over the difficulty of entering equations and chemical structures using a conventional keyboard.

■ CONCLUSIONS

Undergraduates must be given meaningful opportunities to cultivate digital and chemical information literacy, particularly with smartphones. Consequently, a DLN using the free application Evernote was designed. It leverages the unique capabilities of a smartphone but can also be accessed from any Internet-enabled device. The Evernote DLN offers a flexible interface that students customized for an upper-division undergraduate biochemistry laboratory. The DLN can function as a secure data management and storage system, a feature of expensive commercial DLNs. It is compatible with common chemistry applications such as ChemDraw and computing accessories like a stylus to create freehand drawings. On the basis of student feedback and the instructors' observations, the DLN has (1) taught students to collect and organize data more efficiently, (2) contributed to students' digital and chemical information literacy, and (3) because it is accessible across platforms, facilitated collaborative teamwork in a way that paper notebooks could not. The majority of students surveyed (70%)

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would choose to use a DLN instead of a paper notebook in the future. This DLN could be easily adapted for other undergraduate teaching and research laboratories.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.6b00622.

Directions for creating a DLN in Evernote, additional student survey results, and an example entry from a student's DLN (PDF)

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Notes

The authors declare no competing financial interest.

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