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Electronic Laboratory Notebooks Allow for Modifications in a General, Organic, and Biochemistry Chemistry Laboratory To Increase Authenticity of the Student Experience

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Supporting Information

ABSTRACT: When used effectively, laboratory courses can be very important for enriching teaching and learning. However, a review of many colleges and universities across the nation reveals that around 50% of the current Bachelor of Nursing programs have opted to remove (or possibly never included) the chemistry laboratory component. Authenticity is particularly important for prehealth professions students who are required to take general, organic, and biochemistry (GOB) chemistry courses; unfortunately, these students often do not feel the courses are relevant to their future careers. Using three of Herrington and Oliver's nine situated learning design elements, a GOB chemistry laboratory course has been redesigned to implement more authentic activities in the curriculum, largely through the use of an electronic laboratory notebook. The authenticity of the improvements was reviewed by a panel of practicing nurses and nursing faculty, and we report their feedback and evaluation. The general consensus of the panel is that the changes in the curriculum toward more authenticity are a great improvement for prehealthcare professionals.

KEYWORDS: *Chemical Education Research, Laboratory Instruction, First-Year Undergraduate/General, Computer-Based Learning, Laboratory Computing/Interfacing, Nonmajor Courses*

FEATURE: Chemical Education Research

INTRODUCTION

When designed appropriately, the laboratory component of chemistry courses has been found to be important for enriching student learning.[1] Laboratory components of the core chemistry major courses are included in general chemistry, organic chemistry, and upper-level chemistry courses as part of any ACS Certified major program.[1−5] The literature includes reviews of improvements to these courses, which often use inquiry-based learning to increase the authenticity of both the lecture and the lab experience.[6−10] Depending on the course, improvements have often been based on the use of authentic activities such as research-based learning or team-based learning.[11−14] In the literature, these course redesigns are often geared toward students in the science major-serving courses and thus the authentic experiences included tend to center around research activities or research skills that are common to many science fields. Additionally, recent advancements in curriculum alignment, described by the ACS Exams Institute, have outlined general and organic chemistry learning objectives based on assessment materials.[15,16] In particular, concept (IX) emphasizes experimentation, measurements, and data as one of the ten anchoring concepts.[17] This is an important concept because the laboratory experience helps students develop skills such as technical techniques, critical thinking, and data analysis.[2,6,18−21] However, among top programs in nursing, it is common to either remove or never initially include the laboratory component of introductory general, organic, and biochemistry (GOB) course, a course specifically designed for nursing/healthcare professionals. We evaluated the top 50 Bachelor's of Science programs in nursing, according to CollegeChoice.net, and only 24 of them required a laboratory component.[22] To change the trend of removing GOB laboratory courses from the curriculum, we agree with other authors that a focus should be on the authenticity of the experience in these courses.[23−25] However, unlike the core chemistry courses that have often built research-like activities into the curriculum to create authentic experiences, a GOB course should use true clinical experiences as a reference for improving the authenticity and therefore the level of student engagement and motivation. Thus, at Hope College, the GOB laboratory curriculum has been redesigned to emphasize core design principles that focus on authentic experiences according to Herrington and Oliver's framework for authentic learning environments using current literature in Nursing Education and studies into clinical practice.

Authentic experiences and real-world applications have long been implied core design principles for GOB courses, as early

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as 1974 when Stanitski and Sears emphasized a lecture and lab curriculum focused around common wet chemistry analyses that were used in hospital laboratories.[26,27] Much of the day-to-day experience of health professionals has changed since then, including the automation of common chemical tests, and the use of digital record-keeping. Since GOB courses are commonly directed toward future health professionals, it is important for these students to begin learning how to effectively record their procedures and other observations in a notebook. Traditionally, this has been in a paper notebook in most chemistry laboratories. However, as the medical field moves further into using electronic health records (EHRs) exclusively, it is also important for the curriculum to be designed with the intent of helping these students succeed in their future careers.[28] In a recent survey, it was found that 87% of all physicians are using some sort of EHRs, a huge jump up from only 12% in 2007.[29,30] EHRs often utilize specific text boxes for observations, drop-down menus for coding various symptoms, entry forms for specific data, and can also include files such as medical scans, blood test results, as well as photographs. They are becoming the exclusive choice of the medical field because the results can be available by any professional in the hospital at the same time (unlike a paper notebook), and the use of specified text boxes ensures that professionals working with patients record each required aspect at each time. EHRs offer a scaffolded approach to data recording that may seem too restrictive to some chemistry faculty used to traditional paper-based or open-format online notebooks for record-keeping. However, to design a curriculum that is more authentic for the students, we feel it is important to incorporate some sort of electronic record-keeping into a GOB laboratory. In the course at Hope College, approximately 85% of students began the course with a health profession in mind, meaning that the majority of the class would go on to use EHRs if they continued on their noted career path. Thus, the GOB Laboratory course was redesigned primarily with the idea that the laboratories should be made more authentic by way of utilizing an EHR-like record-keeping system throughout all laboratories. This was accomplished by the use of an Electronic Lab Notebook (ELN) designed with specific prompts and scaffolding for data taking and organization.

In addition to electronic record-keeping, the use of technology for practical health applications is also advancing. A 2016 study used cell phone pictures as a way to track a patient's food intake.[31] The cell phone photos proved to be much more accurate than recording food intake from memory, and it is possible that healthcare providers could be shifting to incorporate smart phone applications that improve nutrition counseling for their patients. Thus, the use of actual photographs as a replacement for textual observations is also included in the course redesign. This also allows for students to upload data files and spectra from experiments directly into their ELNs, much like medical scans and reports are contained within an EHR system.

Students are coming to college more prepared to move directly into digital record-keeping. Most current college students are described as "digital natives": those who have been immersed in technology for their entire lives and therefore may learn differently than those who were not.[32] In a recent study, 78% of students preferred to use a digital medium for assignments as opposed to only 14% who preferred paper.[33] In a 2011 study, Williamson et al. outlined several types of innovative technology that can be incorporated into curricula.[34] Some examples include simulation technology, mobile devices (such as smart phones or tablets), and the Internet.[35−37] If these technologies are used in the classroom to assist students in evidence-based decision-making, they can then assist in the students' transition from an academic to a clinical setting. The course redesign to create an authentic experience for students through the use of ELNs to mimic EHR systems is an extension to current work in this field. To create changes that can be evaluated in a meaningful way, the Herrington and Oliver framework was used as a design and evaluation framework.

■ BACKGROUND

Situated learning can be defined as "the notion of learning knowledge and skills in contexts that reflect the way the knowledge will be useful in real life."[38] Herrington and Oliver based their model of instructional design on the theory of situated learning, and elucidated nine design elements. These elements are based on a meta-analysis of the literature concerning student learning in GOB courses. On the basis of their research, the situated learning framework appeared to be successful as an alternative framework of instructional design.[23] Herrington and Oliver use this framework for a fully multimedia course, but here it is used in a technology-heavy real-world lab course. The nine situated learning design elements that Herrington and Oliver focus on in their framework are listed below (Herrington and Oliver, pp. 25−26):

(1) Provide authentic contexts that reflect the way the knowledge will be used in real life.
(2) Provide authentic activities.
(3) Provide access to expert performances and the modeling of processes.
(4) Provide multiple roles and perspectives.
(5) Support collaborative construction of knowledge.
(6) Promote reflection to enable abstractions to be formed.
(7) Promote articulation to enable tacit knowledge to be made explicit.
(8) Provide coaching and scaffolding by the teacher at critical times.
(9) Provide for authentic [integrated] assessment of learning within the tasks.

Although all nine elements were considered when designing the course, Herrington and Oliver's elements 2, 4, and 9 are specifically used here to evaluate the authenticity of the student experience because they rely on expertise that is beyond the knowledge of the instructors. Since the instructors of this course are trained in chemistry rather than in health professions, none of the instructors of this course has worked as a nurse nor worked as part of a team of health professionals at the time of designing the course. Thus, in evaluating elements 2 and 4, an instructor would have difficulty assessing if an activity was being performed authentically or if the multiple perspectives are representative of what a health professional would experience. Also, although instructors have a lot of experience with giving feedback, and often integrated feedback, chemistry instructors are often unaware of what authentic feedback would look like within the context of a health professional's experience.

One skill that is a valuable asset in the healthcare community is providing clear communication of observations and actions,

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which, according to design element 1, should be done in a manner consistent with real life. It has been established that the type of knowledge shared in the health professions community is largely done through EHRs. Thus, LabArchives was chosen as a ELN as it can be modified using templates to create a scaffolded system for students to enter data and share it with other students or their instructor, which incorporates design element 8.[39] This change to the course impacts all laboratory activities in the course. Students can use their laptops, tablets, or cell phones to update their LabArchives notebook during and outside of class. The ELNs give students prompts for what must be included in their documentation, such as procedure, empty tables that need to be filled in, and places to include photos. Documentation occurs through typed-in data entry, photo uploads, and data file uploads. The photos can be annotated with captions so that the instructor can assess how well the student describes his/her observations. Thus, it is required that we assess the use of the scaffolded ELNs to create an authentic experience for our students, as per design element 2.

Before we get into the assessment of the other design elements, it is important to gain an understanding of the course structure and what activities are included. Some activities, in the process of the addition of the ELN, have been improved so that the observations taken also include more authentic experiences. The course we evaluated is "Introduction to Biological Chemistry", a one-semester GOB chemistry course designed for nonmajors. It is a combined lab/lecture course. The class meets three times per week in lecture for 50 min and one time per week in lab for 2 h and 50 min. All laboratory sessions meet on Tuesday, with four sections of 18−22 students each. The lecture portion of the course, which is composed of two sections of 35−50 students each, is generally taught by a tenure-track faculty member, but has been taught by visiting professors in the past. The laboratory portion is taught by adjuncts, full-time instructors, and tenure-track professors over the past three years this curriculum has been implemented. Students always work in pairs or groups during the laboratory session but can either work alone or with others to complete prelab assignments, which are given weekly. A list of the laboratory experiments for the course is given in Table 1.

Table 1. List of Labs

Lab	Experiment
1	Specific gravity and density
2	Testing for anions and cations
3	Dehydration of $CuSO_4$ and $MgSO_4$
4	Hot packs and cold packs
5	Titration of an antacid
6	Antacids and pressure
7	Alkanes, alkenes, and 2D/3D structures
8	Soap making
9	Iron in biochemistry − ferritin
10	Analysis of sugars − urine testing
11	Lipids, fats, and the foods you eat

Here are some highlights of how we modified some of the laboratories to fit the framework of Herrington and Oliver, in addition to the universal change introducing ELNs. There are some lab experiences that have not yet been heavily modified beyond the use of ELNs, so they have not been described in detail. However, those with large changes are also evaluated within design element 2.

Design element 4, providing multiple roles and perspectives, focuses on giving students the opportunity to have more than one investigation within a resource so that students can receive repeated feedback and be able to improve their work. In the revised lab curriculum, students complete prelab assignments on paper that are due each Friday, which the teaching assistants grade over the weekend (out of 3 points), providing feedback for the students. These assignments often involve looking up real-world information about chemicals used in the lab such as examples of oils in foods. These assignments are returned to students on Monday, a day before the experiment is completed in lab, and they are able to make edits and turn in the "pre-lab" again at the end of lab on Tuesday as part of the traditional "signing out" procedure by the TA. Professors grade the edited prelabs (out of 7 points, total of 10 points for the assignment) and return them the following week. These prelab worksheets aim to get students to dig deeper into the lab material by looking up information that is not immediately available to them in their lab manuals or textbooks (design element 4) and use feedback to improve their preparation for lab (design elements 4 and 9). Some of the prelab questions connect knowledge learned from their coursework to a medical concept. An example of a prelab assignment can be found in the Supporting Information.

Providing authentic [integrated] assessment of learning within the tasks, design element 9, focuses on giving students complex and ill-structured challenges that require the use of judgment and problem-solving tactics. Healthcare professionals are faced with complex tasks that require them to use their judgment on a daily basis. It is important that we as educators give them practice on how to solve these dilemmas. One lab that has been designed to provide complex and ill-structured challenges for students is the "Analysis of Sugars" lab. Students perform multiple tests on samples containing known sugars. The known solutions tested include water (blank), several common sugars, and starch. On the basis of the results of several tests on the known solutions, students are given four "urine" samples to determine whether they are normal, diabetic, galactosemic, or fructose intolerant. The students are not told how each of these conditions might show up in the urine and have to figure out which tests will determine these diagnoses. They are given very little direction and must figure out which tests to perform on their own. This lab was modified to include more use of photographs and trials so that students can compare tests with positive and negative controls more easily within the ELNs.

LabArchives also allows for smoothly integrated assessment within tasks. In a traditional laboratory format, students generally turn in a hard copy of their lab report and notebook and receive feedback when the report is returned to them during the next laboratory session. Since feedback is written by hand, it is usually not extensive. With LabArchives, students can receive feedback immediately after the professor has graded the lab report, instead of having to wait a week or more for the next laboratory meeting. Also, instructors can "copy and paste" feedback for common mistakes, so even an instructor who is grading 60 or more lab reports can provide extensive feedback for students. Instructors can also view all of a student's lab work from the semester whenever they are grading, so they can easily track how the student is progressing throughout the semester.

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RESEARCH QUESTIONS

Assessment is an important aspect of curriculum design.[40] Although the instructors of the course are experts in their field of study (chemistry), they may not be experts in the current advances in techniques and skills useful to healthcare professionals. To assess the alignment of the curriculum with the framework, a panel of experts was recruited and a series of semistructured interviews were performed. Through these interviews, we want to address the following research questions:

(1) Using the description provided by Herrington and Oliver, in what ways does the remodeled lab curriculum offer authentic experiences as judged by a panel of health professionals familiar with authentic hospital experiences?
(2) How do the situated learning elements added into the lab curriculum cover the areas that professionals find to be useful in an introductory course, and how can they be improved in the future?
(3) How do the situated learning elements added into the lab curriculum relate to real-world healthcare situations, and how can they be improved in the future?

METHODS

Participants were recruited via an email to all nursing faculty and to local nursing professionals to participate in a one-on-one interview for the purpose of evaluating the quality of the course design and its authenticity. Through the solicitation of practicing healthcare professional participants, the authors were specifically advised to recruit the nurse educator at the local hospital. A panel consisting of two current nursing faculty members (not instructors of the course), one practicing nurse, and one nurse educator from a local hospital participated in individual semistructured interviews according to the framework described by Herrington and Daubenmire.[41] Participants were presented with a description of the course, an explanation of the framework used for redesign, and asked both Likert-style and open-ended questions. The full slideshow used during the interview, including the questions asked, is included in the Supporting Information. A single interviewer administered all interviews and took notes during the interviews, which lasted approximately 30 minutes each. The notes taken during the interviews served as the data for the study. The data required no additional analysis as the participants were in consensus on all of the findings presented here.

FINDINGS

All panelists agreed that the use of LabArchives for documentation is much more authentic to current healthcare practices than using paper notebooks. Though LabArchives is not exactly what students will be using when they become practicing health professionals, the outline that provides charts and guiding questions in the LabArchives modules relates more closely to EHRs used in the clinical setting than traditional lab notebooks. This is because nurses are generally asked to “fill in the blanks” or select answers from a drop down menu, rather than writing free hand. There is not a streamlined program used by all hospitals and clinics, so each EHR will be slightly different. Thus, though it is not an exact replica of what they will be using in practice, it is necessary for the students to know how to document information electronically and the use of LabArchives is contributing to that ability. All four panelists also mentioned that the LabArchives experience could be more authentic if all of the free writing portions were taken away and only drop-down menus with very small amounts of actual typing were included. However, they recognized that this could take away from the scientific inquiry and learning of the student, so there is a balance between true authenticity and helpfulness for their learning that would need to be found here.

Another suggestion arising from the panel involves data and knowing how to access it. Nurses may not always be the one filling in the charts; they will also have to access and interpret data that others have recorded. The panel encouraged the researchers to make sure that each lab is pushing students one step further toward their critical thinking by making them interpret what they are doing. Practicing healthcare professionals must have highly developed critical thinking and problem solving skills to be successful in their field. One way to push the students to think further about the results of their lab experiments had already been implemented into the curriculum by adding a section with questions about the results at the end of each lab, but could be taken further, as noted by agreement by all members of the panel.

LIMITATIONS

Because the new lab curriculum was only analyzed by a small panel of practicing nurses and faculty, it is possible that others would have different opinions on the authenticity of the laboratory activities. However, since there was such strong agreement among the panel and the panel consisted of both practicing nurses and nursing faculty members, the authors decided that conclusions could be drawn from their opinions.

IMPLICATIONS AND CONCLUSIONS

The use of Electronic Lab Notebooks was unanimously seen as a move toward a more authentic learning experience for students going into the health professions. Indeed, it was suggested that less free-response in recording observations may even be a more authentic experience. This feedback genuinely poses a new problem within the Chemistry Education Community: what are the learning objectives for a laboratory that does not allow for independent observations? Within the health professions community, it is absolutely necessary that each observation be universally recognized and as such correspond to a specified code.[42] In the year following this analysis, for instance, the course was modified so that instructors told students that all observations of solutions must include either the word “clear” or “cloudy” and trained students in how to use those two words specifically and identify their characteristics. In the future, perhaps GOB courses will need to have quite different learning objectives for laboratory data-keeping than their counterparts in the core chemistry courses. This could be implemented, as the panel suggested, by bringing more interpretation of existing data in to the laboratory setting. This could be done by having a data analysis-style laboratory where actual test results from a hospital could be analyzed in lab, or a laboratory activity could have students rely upon the systematized observation-taking of another group’s data. The analysis portion of the data interpretation could also be incorporated into the lecture, however, as lab time may be best used for the recording of data. This information literacy aspect of documentation and health records is worth further research as others work on design of a GOB course in the future.

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EHRs have been implemented in nursing education clinical laboratories through the use of special academic tools that simulate actual patient data, mimicking what is being used clinical practice.[43−47] This further presses the importance of ELN use to prepare students for the use of these tools in other courses. They have been well-received by students and faculty,[43,47] and have been shown to increase critical thinking skills[47,48] and improve accuracy in identification of patient data.[49] Aspects of these tools could be added to the GOB chemistry curriculum to further connect what students are learning in chemistry to skills that will be required for their future careers. The use of ELNs in their required chemistry courses could serve as a link between experimental chemistry and work in a clinical setting. The use of realistic patient data, like that included in academic EHR tools, is a useful addition to the GOB chemistry curriculum. For example, adding a part to the "Analysis of Sugars – Urine Testing" lab where students are given realistic patient data to analyze following the experiment would further familiarize students with evaluating patient data and drawing conclusions.

It was also suggested by one panel member that all lab activities should make clear how they are authentic to students. Students will be more likely to learn from these activities if they compartmentalize them as something that they can use in the future for their career. Many prehealth professions students see their GOB chemistry course as a necessary hurdle for them with no direct benefit to their career. However, the goal of the curriculum redesign was to provide the students with authentic activities that will aid them in their professional careers. For example, students need to do stoichiometry calculations in chemistry, which many of them do not relate directly to what they will do in a health professions career. However, unit conversion calculations directly relate to the drug calculations for weight-based doses that nurses complete each day. One suggestion was that students are shown a drug conversion calculation along with a stoichiometry calculation so that they can recognize how valuable the chemistry course is to them as health professionals. It was noted by the nursing faculty in the panel that students learn this skill in their freshman year but do not realize it is useful to their careers until their junior or senior year, when they start specifically learning about drug calculations. In the future, the course could be further evolved to demonstrate to students how each lab is beneficial to their future career, even if it is not immediately obvious to them. For instance, perhaps in addition to the "Learning Objectives" list that is present at the beginning of each lab, an instructor could include a "How this applies to my future career" section. As further evidence that connectivity of the chemistry curriculum to nursing practice is highly relevant, Boddey and de Berg found that first-year nursing students found the connections to nursing to be a highly important part of the curriculum.[50] The more connections the students found, the more relevant they felt that chemistry was to nursing. The students also enjoyed chemistry more when they felt they could relate to it. Some examples of chemistry topics that students felt were relevant to nursing include osmosis and edema, and pH and buffers. For future improvements to the laboratory curriculum, lab activities that make connections between chemistry and nursing in these topics should be considered.

All of the authors have taught the GOB laboratory course over the past three years. Although we have no data other than our own consensus, it is evident to all of us that it is much easier to get students to write more detailed and complete laboratory notebooks when the context of real-world EHRs is given. The focus of the lab has become one of documentation rather than training students to write a scientific notebook as we had been trained as chemists. In fact, there are options within LabArchives for sharing lab notebook data from student to student, but it has not been implemented so far in the course. Shared spreadsheets and class data has been used to have students make inferences beyond their own data; however, more work can be done to figure out how to use data-sharing and whether the methods used in these changes are authentic and build student learning.

Last, it is important to think seriously about how to get students to engage with real-world data and push their critical-thinking skills, as suggested by the panel. Because this course is designed as a companion to the lecture, many of the laboratories are tied to lecture material. Since the conclusion of these interviews, however, we have incorporated two main changes to the curriculum to get them to engage with existing data in the real world: a new lab where they identify structural components of organic compounds listed on food labels and drugs (integrated after Lab 7 in Table 1), and replaced a lab exam at the end of the semester with an oral presentation where groups of students present the biochemical pathways of a chosen disease, and how a drug molecule interferes with that pathway. These two laboratories require students to engage with actual external data (they bring in their own food labels, for instance), and with Web sites for drug companies to understand the organic and biochemical nature of these substances and processes. In the future, it would be beneficial to work with nursing professionals to assess the authenticity of these practices and to perform the research to support the immense positive feedback we experienced from our students from these two new laboratories.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.8b00140.

- Full list of laboratories performed with short summaries and learning objectives (PDF)
- Copy of the slideshow used during interviews with panel (PDF)
- Example prelab assignment key (PDF)

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Author Contributions

A.J.D. performed the research and writing of this manuscript while a member of the Hope College faculty as a Visiting Instructor in 2017. She currently is pursuing her Ph.D. in Chemistry Education at University of South Florida. L.M.J. initiated the redesign of the course at Hope College while a Visiting Assistant Professor in 2016 and has remained active in the continued redesign and in the design of this research project.

Notes

The authors declare no competing financial interest.

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