Usability Testing and the Development of an Augmented Reality Application for Laboratory Learning

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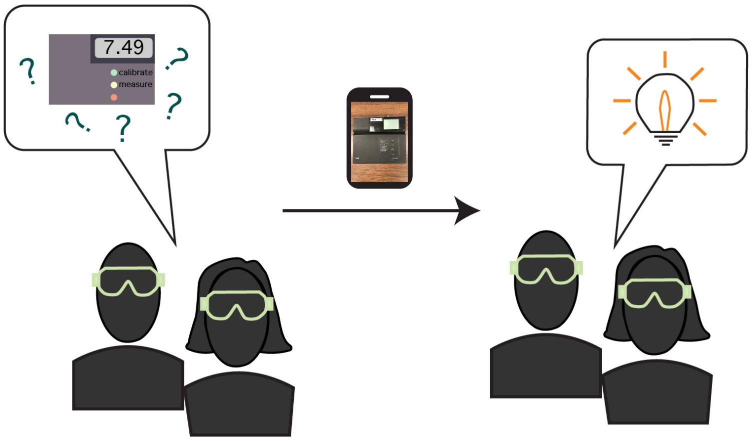
ABSTRACT

In general chemistry laboratories, students learn practical laboratory skills through hands-on activities and are exposed to new scientific instruments. However, these instruments are often viewed as black boxes for various reasons, where students do not know how to use them or what the instruments are capable of. This tendency is likely to induce some measure of fear in the students' attitude towards learning about instruments, even though instrumentation is a significant part of laboratory education. Augmented Reality in Educational Laboratory (ARiEL) is an application utilizing AR technology designed to connect students to information on scientific instruments. ARiEL can be downloaded and used on phones or tablets while students are working on experiments, providing them with direct and immediate forms of information about laboratory instruments. Currently, pH meter and conductivity meter are two instruments ARiEL can recognize as they are small, benchtop devices often used in general chemistry laboratory courses. An initial usability study with a focus group of first-term general chemistry students indicated that the application is not only easy to use but also preferred over a common search engine when looking for information on specific instruments. The application was used in a second-term general chemistry laboratory course and tested for usability evaluation and to measure students' attitude towards chemistry instrumentation. The results suggest that the availability of ARiEL helps to reduce anxiety associated with using instruments and to improve intellectual accessibility.[†]

[†]This paper includes results first reported in a presentation given at 2018 Biennial Conference on Chemical Education (BCCE), #109, July 2018.

GRAPHICAL ABSTRACT



KEYWORDS

First-Year Undergraduate/General, Laboratory Instruction, Internet/Web-Based learning, Laboratory Equipment/Apparatus

INTRODUCTION

Chemistry courses in higher education are often designed to be divided into two parts – lecture and laboratory. In lecture, students learn fundamental knowledge of chemistry, whereas in laboratory, students are introduced to chemicals, practical skills, and various apparatus and instruments. To list a few, goals of laboratory courses are said to be (1) stimulate and sustain interest in science, (2) promote creative thinking and conceptual understanding of science, (3) develop practical skills, and (4) develop inquiry skills.[1-4] Laboratory courses have always been considered to be important, and many educators have argued that laboratory must be an integral part of science education.[3-6] Despites these widely held beliefs, some researchers suggest that there is no concrete evidence supporting the beneficial nature of laboratory courses.[3,7] In fact, certain studies have found that students focus predominantly on procedural details rather than understanding and connecting the theoretical knowledge from other aspects of science courses to experiments.[8-9] Laboratory courses can provide a valuable learning experience for students in chemistry, but in order for meaningful learning to occur, courses must be constructed effectively.[9] The argument for building efficient laboratory course structures may be especially true, given the high cost of time, labor, and materials associated with laboratory courses.

There are a number of studies that focus on improving chemistry learning in laboratory courses, and some of these methods include reconfiguring the structure of the course or adding technology to enhance students' learning experiences. For example, Veiga et al. implemented interactive online pre-laboratory tools in a general chemistry laboratory course.[10] The interactive pre-laboratory material included audio, text, images, video, external links, and interactive fields of all necessary information for an experiment such as its theoretical background, materials, experimental protocol, and safety. Students could choose which material they wanted to interact with for each section of their pre-laboratory work, or they could simply choose to use the traditional written experimental manual instead. The study found that over 60% of students chose interactive materials consistently, and this was especially true for the low performing students. Stieff et al. also studied the use of online video and face-to-face pre-laboratory materials in general chemistry laboratory to improve students' understanding of experimental procedures.[11] Based on the results of average achievement scores of laboratory activities as well as the time it took for students to complete the experimental procedures, they found that the online video pre-laboratory was more effective in improving student understanding of laboratory procedures when compared with face-to-face lectures.

Augmented reality (AR) is an emerging technology, a platform where physical and virtual worlds are combined together. The use of AR technology in educational settings, especially those of STEM, has increased significantly in the past few years. For example, AR has been applied in laboratory classes in engineering courses to create a remote laboratory tool that students can utilize without physically being present in schools,[12] to create an interactive, collaborative learning environment,[13] to help students learn about machinery operation,[14] and as an interactive experimental manual.[15] More recently, application of AR technology in various chemistry courses has been reported. For instance, several studies have used AR to better represent 3-D molecules that are otherwise represented in 2-D format,[16,17] aiding students in visualization of molecules. An application utilizing both virtual reality (VR) and AR has been presented by Chiu et al., designed to assist students in learning stereochemistry and molecular interaction in organic chemistry.[18] In addition, it is also possible to apply AR in chemistry laboratory courses. Huwer et al. developed an AR application to include targeted assistance and visualization tools for students to utilize during an electrochemistry experiment.[19] Through this app, students were able to interact with the AR interface to find help and view information in image or video format, and students who used the AR interface with dynamic resources showed enhanced performance compared to those who used analogue resources.[19] A different AR-based application was developed by the same authors to help students reach more information about safety symbols used in chemistry laboratories using a non-traditional method to attract students' attention.[20] A virtual laboratory tool, where the application is used as a pre-laboratory exercise to aid in students' learning of experimental manipulation as well as their understanding of concepts, has also been introduced.[21] In this study, they found a significant improvement in students' understanding of chemistry experiment concepts using the developed tool.[21] Most recently, Naese et al. reported an AR application that was designed to help students collect more information about instruments used in analytical laboratories, such as spectrometers and chromatographic instruments.[22] While the study did not measure specific quantifiable outcomes of student performance, many students who used the application had favorable reactions to the availability of such AR tool.[22]

One key aspect of experimental science that has yet to attract the attention of technology development to the same extent in the chemistry laboratory setting is the role of procedural knowledge related to chemistry instrumentation. Chemistry experiments often utilize various instruments to measure observable and unobservable changes. While these instruments enable science to progress and allows scientists to make measurements of nature that would otherwise be unobserved, they are often overlooked in many science courses,[23] including chemistry. Given that similar applications of AR in chemistry laboratory courses have resulted in positive outcomes and feedback from students, the hypothesis is that this specific aspect of laboratory learning can be improved with AR technology.

Here, we introduce the interface that connects information with chemistry instruments that can be used in general chemistry laboratories, by means of AR technology. Augmented Reality in Educational Laboratory (ARiEL) is designed to be a highly accessible application to which students can download on their phones or tablets. The overall purposes of this project were (1) to develop a tool that can be used by students while performing experiments, providing them with immediacy of information on instruments they may otherwise view as "black boxes", and (2) to investigate the potential influence this tool has on students' attitudes towards chemistry instrumentation. Initial instruments that were chosen for the development of this application were pH meter and conductivity meter, as these are small, benchtop instruments commonly used in general chemistry laboratories. The development process of the ARiEL application, implementation study in focus group and General Chemistry II Laboratory course, usability results, as well as the future direction will be discussed in this paper.

METHOD / METHODOLOGY

Development of ARiEL

The overall goal was to develop an AR-interface application that can recognize instruments used in chemistry laboratories via an onboard device camera and provide users information about instruments. In order to create the ARiEL platform, the Vuforia software development platform was used. Vuforia is an augmented reality software development kit (SDK) for mobile devices that enables the creation of AR applications. It uses computer vision technology to recognize and track planar images and simple 3-Dimensional (3D) objects. The image registration capability allows the developer to position and orient virtual objects, such as 3D models and media, in relation to the real-world object viewed through camera of mobile device, thus augmenting the real-world object with a virtual object or media. The Vuforia SDK supports a range of recognition capacities so that AR applications can be designed to incorporate various features, including recognizing the actual instruments as was deployed for the current work.

Many instruments in introductory chemistry laboratory settings look somewhat similar, so a key capacity for AR applications is the ability to distinguish between such similar objects. For this feature to work well, the physical object must be opaque, rigid, and used in indoors, typically on a tabletop. The Vuforia object recognition feature allows applications to detect and track intricate 3D objects using a target, which is a digital representation of the features and geometry of a physical object. To create these targets, Vuforia Object Scanner software scans the instruments. The resulting object targets are then uploaded to the Vuforia database. Once this process is complete, the mobile application is then able to recognize the target objects upon pointing the camera at the instruments. The two instruments for which an AR interface has been developed in ARiEL are pH meter and conductivity meter, which are often introduced to students in acid-base experiments performed in general chemistry laboratory courses. The specific models of instruments used in this project were Orion 410A pH meter and Orion Star A112 conductivity meter from Thermo Scientific (Waltham, MA, USA). In order for different models or types of instruments to be recognized by ARiEL, separate object targets must be created by the scanning and uploading process just described.

Once the instruments have been recognized by Vuforia object recognition software, it was necessary to develop an interface in which users can engage. This capacity is developed using the Unity3D engine. Thus, software generating tools which ultimately build the application program interface (API) in C Sharp programming language (C#) are used to create the user interface component of the AR application. The API itself is organized in "scenes". For any scene defined by the developer, several different objects or action tools can be part of the User Interface (UI). Thus, the resulting UI can be customized to correspond to any instrument, or for any experimental use of an instrument. At present the ARiEL interface includes four buttons – Operations, Calibration, Safety, Experiments. Each of these buttons takes the user to a new "child scene", which is linked to an external website containing appropriate information about the instrument. The title and buttons appear as a screen-space overlay on the camera generate image, so these aspects of the UI are floating on top of everything else within the scene. The scene size adjusts automatically according to the scene dimension for the device on which ARiEL is being used. This feature allows the development of an application that can be used on phones, tablets, or even laptops. Figure 1 provides an example of how the buttons show on the screen upon recognition of instruments, as well as examples of the web pages students can visit by clicking on the buttons.

Information connected to the "Operation" button includes what the instruments measure and how the probes work to make such measurements. This section also includes the use of each instrument for various "Applications", such as how, when, and where they are used outside of the teaching laboratory. The "Calibration" option includes video demonstrations of how to calibrate the instruments along with step-by-step instructions for calibration. Various safety information on chemicals and probes used with the instruments is listed under the "Safety" tab. Lastly, "Experiments" button is connected to files of experimental manuals that they would be able to perform with each instrument.

Figure 1. Screenshots of instrument recognition by the ARiEL application on an Android phone and the resulting connections to example, mobile-optimized web pages.

The final step in the app development process was to convert the Unity project file into applications suitable to be run in Android and iOS systems. The Android version of the application was built using Android Studio, which allows the application to be run in system versions as low as Android 4.0. Project Builder for Unity software was used to build the iOS version of the application. The use of Apple Developer Program was necessary to work with any iOS devices, whether it is for beta testing or uploading the application to AppStore. For the implementation study, ARiEL was made available as a beta version for open testing purposes in both Android and iOS markets.

Implementation and Evaluation of ARiEL

The following studies were undertaken in several stages to determine the usability of the ARiEL application and to seek preliminary evidence of how it might affect student impressions of laboratory learning. These studies took place in a large public research university in the Midwest region of the United States in the Fall 2018 and Spring 2019 semesters.

Phase 1: Focus group usability study

Phase 1 was determined to be an exempt study by the Institutional Review Board. In Fall 2018 semester, a focus group study was completed with 12 students from General Chemistry I lecture who were taking the course for honors credits. None of these participating students identified themselves as chemistry majors, but the students were pursuing degrees in related scientific fields that include general chemistry as part of their curriculum. The focus group study was carried out in two separate 50-minute sessions with six students in each session. The participating students were added to the list of beta testers and were given access to download the beta version of the application on their iOS devices.

At the start of each focus group, students were asked a few questions regarding their general method of preparation for laboratory classes. After the discussion, students were directed to download and use the ARiEL app for about ten minutes with versions of both the pH meter and the conductivity meter. They were also encouraged to look through the information presented on the associated websites to evaluate the applicability. Once they had ample time to explore how the application worked with each instrument, additional questions were asked about their impressions of ARiEL and chemistry instrumentation. The initial discussion questions are provided in Table 1. Follow-up questions were also used in the focus based on student responses to these initial questions. Students were then asked to complete System Usability Scale (SUS)[26] based on their experience (Table S1).

Table 1. Initial Discussion Questions for Focus Group Study

Question
1. How do you prepare for your regular laboratory periods? (Pre-app)
2. How would you describe your general thought process when you are about to use a new piece of apparatus or equipment (instrument) in chemistry laboratory? (Pre-app)
3. Now that you have used ARiEL interface, would you choose a search engine or ARiEL to use in your laboratory courses when you want to look up information about the instrument you are using? Why? (Post-app)
4. Do you think it is important to learn how to use these instruments? Why or why not? (Post-app)
5. How do you think this tool can be made to be more helpful? (Post-app)

Phase 2: Class-scale implementation

This study was based on voluntary participation and was approved by Institutional Review Board prior to the experiment. In the Spring 2019 semester, ARiEL was implemented in a course for the first time. General Chemistry II Laboratory course was selected for the implementation study because the course utilizes both pH meter and conductivity meter in various experiments. ARiEL was implemented during the sixth week of the semester in the experiment where both instruments are used to measure pH and conductance levels of acid, base, and salt solutions, giving students ample opportunities to try out the application on both instruments during the laboratory period. The General Chemistry II course at the University are taken by students of various majors, with many students majoring in STEM areas such as engineering or kinesiology. For this implementation study, new challenges arise due to the structure of general chemistry laboratory courses, both in terms of the number of students and the fact that laboratory periods are spread over several days. As is true at many larger universities, labs are taught by teaching assistants who also needed some basic information about the project prior to when students might make use of ARiEL. To be certain teaching assistants were comfortable with the ARiEL application, information on how to download and access it was discussed during the weekly laboratory staff meeting before the experiment, and the teaching assistants were asked to encourage students to use ARiEL during the target experiment.

Students were asked to complete a pre-survey before the experiment, download the application, and complete a post-survey after the experiment. Links to the app downloading page as well as the downloading instructions were provided to the students with the pre-survey. Pre- and post-survey links were open for a week prior to and after the target week, respectively, ensuring enough time for students to provide feedback before and after the experiment. Pre-survey consisted of 4 demographic questions (student ID, sex, major, and number of chemistry courses taken) followed by the modified version of the Attitude towards Subject of Chemistry Inventory (ASCI).[24] In the post-survey, students were asked to rate the difficulty of app downloading experience and to indicate the OS type before completing ASCI followed by SUS. For the ASCI survey portion, participants were specifically prompted to consider their experience with laboratory instruments in the context of having the ARiEL tool available for use with instruments that are part of laboratory instruction.

The original version of ASCI measures students' attitudes towards chemistry using 20 semantic differential items. In this study, the aim was to find students' general attitudes about working with instruments in chemistry laboratory rather than the chemistry subject. Xu and Lewis created ASCI (V2),[25] a shorter version of ASCI containing only two subscales (Emotional Satisfaction and Intellectual Accessibility). For the current study, areas such as anxiety and level of interest were thought to be important measurements in studying what students think about instrumentation. Therefore, the original ASCI (V1) was employed in this study, but it was modified to refer to "Chemistry instrumentation", rather than the subject of "Chemistry". All other components of the inventory, such as instructions and semantic differential scales, were kept identical to that of the original version.

DATA ANALYSIS

Approximately 400 responses were recorded for the pre-survey and 300 for the post-survey, but only the responses from students who had taken both pre- and post- surveys and who used the app during the experiment were retained for the analysis. In addition, when the response pattern included the same answers for all items, missing more than one answer, or if responses came from students who did not give consent to participate in the research study, they were removed before analysis. Using the student ID numbers collected with the surveys, students' pre- and post- survey responses were matched. After the data screening process, the total number of ASCI and SUS responses remaining for further statistical analysis was 104 and 97, respectively. Of the 104 samples, 43.3% of respondents were male and 54.8% female, with one no response and one student who 'preferred not to respond'. The breakdown of indicated majors is as follows: 27.9% engineering (including civil, computer, chemical, and materials), 26.0% biology, 21.2% kinesiology, and 24.9% other similar areas such as genetics, animal ecology, psychology, etc. The number of chemistry courses that involve laboratory taken by students before General Chemistry II was one (17.3%), two, (50.0%), three (26.0%), and four or more (6.7%). This demographic data suggests that about half of this specific population of students seemed to have taken one college level chemistry course (General Chemistry I, most likely) and one high school level chemistry course.

Since its introduction, SUS has been widely applied as a rapid way of measuring usability of technology-based applications.[26] The survey contains 5 positively worded questions and 5 negatively worded questions, and it utilizes a 5-point Likert scale. The SUS scoring rubric[26] uses reverse scoring for negatively worded statements and is scaled to result in a score ranging from 0 to 100. A score of 100 indicates the most ideal level of usability, whereas a score of 0 represents the poorest system usability. SUS results obtained from both Phase 1 and Phase 2 studies were all scored using this previously established rubric.

All statistical analyses were carried out using the R software system.[27] Skewness and kurtosis were determined for each item of the ASCI (pre- and post-survey), and all items possessed normal response distributions. Exploratory factor analysis (EFA) was performed to investigate the structure of the ASCI data. The maximum likelihood with oblique rotation method was employed. In order to determine the appropriate number of factors to extract, a scree plot was constructed (Figure S1). Upon testing three to five factor extractions, 4 factors were extracted following the previously published reports .[24,25] Based on the EFA results, internal consistency was measured by calculating Cronbach's α of each subscale. Scores of each subscale in percentage were calculated according to the literature,[24] where scale 1 = 0% and scale 7 = 100%. A paired t-test was performed on each item of ASCI to assess any changes in students' attitude towards chemistry instrumentation after being introduced to ARiEL system.

RESULTS AND DISCUSSION

Focus Group Study

The first question (Table 1) was asked to understand the degree of preparation that students engage in before each experiment, as preparation is an essential part in laboratory learning.[8] All students agreed on their method of preparation to be reading the written manual, rewriting the procedure, and completing pre-laboratory quiz, which are all required tasks of the course before each experiment. The second question was asked to gauge the students' attitudes and thoughts when faced with new instruments in the laboratory. Students expressed that they generally do not think about instruments or their use on their own before or during experiments. Rather, the primary action is to rely on their teaching assistants to guide them through the instrumentation portion of the experiments.

Students were then directed to download and interact with the beta version of the ARiEL application on their iOS devices. A majority of the students had little to no experience with AR technology, with the most common experience being the use of the Pokémon Go gaming application. With little instruction given on how to use the application, students were able to quickly access ARiEL. For about ten minutes, students were encouraged to (1) explore how the application works with both the pH meter and conductivity meter, (2) look at the information provided for each instrument, and (3) focus on how usable the application appeared to be. The first question asked after interacting with ARiEL (Table 1) was whether they would choose a generic search engine or ARiEL when they desire to know more information about instruments during experiments. Eleven out of twelve participating students expressed they would much prefer ARiEL over a search engine for one or more reasons, and the reasons were: (1) ARiEL can recognize the specific instruments they are using, (2) it is a more direct way to get to information they would need in that moment, and (3) that it is much faster than looking for relevant information among the many entries that would be provided by an internet search engine. The student who preferred a search engine over ARiEL stated that they would still like to be able to sift through information on their own.

These results are important in that they suggest the core concept of making an AR interface available to students is able to call attention to the role of a laboratory instrument in the learning of experiments which tends to predict some value to technology-comfortable students. While the initial focus group work has a pragmatic goal of establishing fundamental usability for the interface, the ability to direct attention to important tasks represents a well-studied, and important aspect of AR interfaces, particularly for tasks that require physical manipulation of objects, such as assembly tasks.[28,29]

Instruments are fundamentally a valuable component of many chemistry experiments, but to find ways to improve student learning in this area it is necessary to know how students view the use of instruments. When asked their opinions on the importance of learning instrumentation (Question 4, Table 1), all students answered that the importance is highly ranked. Students agreed that the reason for such importance is because possibilities of transferring the knowledge to their own fields of interest is high. It was also mentioned that instruments enable them to complete experiments, and that knowing how to use instruments correctly is of a significant importance in carrying out experiments in the right way.

The usability aspect of the application was measured by SUS questionnaire.[26] SUS items and the median values obtained in the focus group study are shown in Table S1 of supporting information. The participating students felt confident using the system, even though it was their first time being exposed to the application. In addition, there was a general agreement among the students in the focus groups that the system was easy to use, and that its functions were well-integrated. Calculation of the responses based on scoring scheme resulted in average usability score of 88.75, which is comfortably higher than the SUS score of 70 that is indicative of acceptable usability.[30]

Implementation Study

App downloading

The app was available as a beta version for two operating systems (OS), iOS and Android. A majority of the students used the app on iOS devices (77%), and a smaller number of students used the app on Android OS (23%). The experience of app downloading was rated as extremely easy (21.2%), somewhat easy (43.3%), neither easy nor difficult (21.2%), somewhat difficult (12.5%), and extremely difficult (1.9%). Since the app was a beta version, the downloading process for iOS platform was slightly more complicated than a regular app from the App Store, where students were required to download Apple's beta testing app in order to have access to ARiEL. Given this, it is understandable that some portion of the students felt that it was difficult to download ARiEL app. Nevertheless, over 60% of the participating students indicated easy downloading experience.

Usability

The primary goal of the first implementation study was to get a better idea of the app usability from a bigger sample size, by having students use the app in actual laboratory settings. The analyzed responses yielded 69.5 in SUS score, which is also at the acceptable SUS score, though not to the extent of the earlier, more personalized experience in the focus group phase. Even though the SUS score is lower in the larger implementation, studies have shown that this score is especially strong for a new system, before any changes are made based on extensive user feedback.[30] Ultimately, there are several possible reasons for the difference in score: (1) students in Phase 2 used ARiEL in the laboratory setting while carrying out the experiment whereas focus group study was carried out in a non-laboratory environment, (2) responses were collected from a larger number of students in Phase 2 and they were less likely to be interacting with the application developers, (3) support was more readily available for the focus group students as the researchers were present during the study, and (4) the focus group students were aware that the system was in its initial test of any kind, and felt they were entrusted with a special role, which may have resulted in inflated positive perceptions.

Attitude measurement using ASCI

Beyond the ability to create an interface that helps students interact with the practical matters of chemical instrumentation, evaluating how the interface may affect students is important. It is easy to imagine the general mystery associated with instrumentation results in students perceiving merely that they provide numbers to be used in an academic exercise, more so than they provide an ability to interrogate nature in a more robust manner. As noted in the Development section above, the "Operations" link in the ARiEL application specifically includes information about applications of the instrument outside of the instrument lab. While it is not possible to correlate student access to such information with the anonymous survey results, it was hypothesized that knowing students' attitudes about instrumentation would begin to help with understanding how chemistry instruments are viewed to students. This is a topic that has not been previously measured, so the initial attempt was to use a previously developed instrument, the ASCI (V1),[24] and adapt it to be on instrumentation by changing the stem phrase from "Chemistry is…" to "Chemistry Instrumentation is…". This change could result in very different psychometric behavior for the instrument, so measures of validity have been pursued.

In the original publication of ASCI (V1), four factors were extracted, namely, Interest & Utility, Intellectual Accessibility, Anxiety, and Fear. While the first three factors each contained five items, only one item was loaded onto the 'Fear' factor. In addition, the remaining 4 items were considered as 'Emotional Satisfaction' subset, as these items had low loading values towards several of the extracted factors. In 2011, Xu and Lewis reported a repeat of ASCI (V1), and their EFA results were not in perfect alignment with the original data.[25] For example, 3 out of 5 items in the 'Anxiety' factor loaded onto other factors, and items in 'Emotional satisfaction' subscale also showed higher loading values towards other extracted factors.

EFA results on the Chemistry Instrumentation version of the ASCI from the Phase 2 are shown in Table 2, and item mean scores are shown in Table 3. The first factor, which includes four items (#1, 4, 5, and 10), was named Intellectual Accessibility. Besides the fact that #9 is not included, these four items in the first factor are identical to the Intellectual Accessibility from the original report.[24] Mean scores for these items are 3.85, 3.71, 3.96, and 3.63, showing that students mostly feel instrumentation is not intellectually accessible. Factor 2, named 'Enjoyability' contains 5 items (#3, 7, 8, 12, and 13). Average scores for these 5 items are 3.77, 3.84, 4.52, 3.28, and 4.40, which suggest that students generally feel that chemistry instrumentation is more exciting, satisfying, fun, interesting, and attractive. Factor 3, which was named 'Satisfaction', includes 3 items (#2, 11, and 15) that look at worthiness and interest aspects. Mean value for item 2 is 5.28, suggesting that students feel instrumentation is very beneficial, supporting the feedback received during the focus group study. The other two items show mean values of 3.76 and 3.20, also suggesting that students feel it is pleasant and worthwhile to work with instruments. Factor 4 has four items (#14, 18, 19, and 20) which all inquire the level of anxiety associated with instrumentation. The average scores for these four items are 3.55, 2.86, 3.82, and 4.35, as shown in Table 3. While the results do not indicate that instrumentation is particularly anxiety provoking for students, the mean values are still close to the middle (4) for most of these items, suggesting that it is still possible to improve the level of comfort they feel around the instruments. The remaining 4 items (#6, 9, 16, and 17) did not show loadings above 0.4, meaning they were not strongly associated with any of the 4 factors that were extracted.

To examine the internal consistency of the extracted factors, Cronbach's α value for each of the 4 subscales was calculated. The Cronbach's α values were found to be 0.83 for Intellectual Accessibility, 0.80 for Enjoyability, 0.78 for Satisfaction, and 0.73 for Anxiety subscale. These values are all above the generally acceptable cutoff of 0.7, indicating that items in each factor are closely related. While there were four items that did not exhibit high loading values towards any single factor, the 4-factor structure with 16 items is supported by the adequate internal consistency. It is important to note at this point that ASCI used in this study attempted to measure attitude specifically towards chemistry instrumentation, rather than chemistry as a subject. Given this, it is not entirely surprising that the factor structures for this study are different from those of the original report.

Table 2. Exploratory Factor Analysis Item Loadings for ASCI (V1) Measuring Attitude Towards Chemistry Instrumentation

Items	Polar Adjectives		Factor 1	Factor 2	Factor 3	Factor 4
Intellectual Accessibility						
1*	Easy	Hard	**-0.48**	0.24	0.05	0.11
4	Complicated	Simple	**0.85**	0.08	-0.08	-0.01
5	Confusing	Clear	**0.71**	-0.14	-0.09	-0.07
10	Challenging	Unchallenging	**0.81**	0.07	0.07	0.04
Enjoyability						
3*	Exciting	Boring	0.07	**0.65**	0.15	-0.11
7*	Satisfying	Frustrating	-0.21	**0.41**	0.18	0.31
8	Scary	Fun	0.08	**-0.73**	0.11	-0.03
12*	Interesting	Dull	0.34	**0.46**	0.38	0.14
13	Disgusting	Attractive	-0.08	**-0.52**	-0.15	-0.08
Satisfaction						
2	Worthless	Beneficial	0.04	-0.07	**-0.65**	0.05
11*	Pleasant	Unpleasant	-0.29	0.22	**0.42**	0.18
15*	Worthwhile	Useless	-0.06	-0.01	**0.89**	0.03
Anxiety						
14	Comfortable	Uncomfortable	-0.09	0.16	0.12	**0.45**
18	Safe	Dangerous	0.10	-0.26	0.02	**0.63**
19*	Tense	Relaxed	0.22	-0.15	0.23	**-0.68**
20*	Insecure	Secure	-0.05	-0.02	-0.18	**-0.72**
6	Good	Bad	-0.14	0.16	0.31	0.39
9	Comprehensible	Incomprehensible	-0.32	0.14	0.26	0.26
16	Work	Play	0.12	-0.35	0.22	0.19
17	Chaotic	Organized	0.05	0.04	-0.27	-0.36

[a]*EFA* with maximum likelihood method and oblique rotation.

* = scales reversed when averaging the score.

Table 3. Average Values of Responses for Each Question from Pre- and Post-survey, Mean Difference, and p-values.

Item[a]	Polar Adjectives		Response Mean			
			Pre-survey	Post-survey	$\lvert \mu_d \rvert$[b]	p-value[c]
1	Easy	Hard	3.85	3.44	0.404	0.009
2	Worthless	Beneficial	5.28	5.22	0.058	0.064
3	Exciting	Boring	3.77	3.74	0.029	0.858
4	Complicated	Simple	3.71	4.12	0.404	0.007
5	Confusing	Clear	3.96	4.26	0.298	0.046
6	Good	Bad	2.96	3.03	0.068	0.597
7	Satisfying	Frustrating	3.84	3.60	0.240	0.084
8	Scary	Fun	4.52	4.48	0.038	0.751
9	Comprehensible	Incomprehensible	3.28	3.08	0.202	0.143
10	Challenging	Unchallenging	3.63	3.67	0.035	0.891
11	Pleasant	Unpleasant	3.76	3.49	0.269	0.054
12	Interesting	Dull	3.28	3.30	0.019	0.889
13	Disgusting	Attractive	4.40	4.39	0.010	0.936
14	Comfortable	Uncomfortable	3.55	3.30	0.250	0.078
15	Worthwhile	Useless	3.20	3.06	0.138	0.387
16	Work	Play	3.09	3.18	0.095	0.487
17	Chaotic	Organized	4.57	4.61	0.033	0.900
18	Safe	Dangerous	2.86	2.54	0.317	0.037
19	Tense	Relaxed	3.82	4.23	0.413	0.007
20	Insecure	Secure	4.35	4.65	0.308	0.012

[a] items were not reversed for this analysis.

[b] absolute value of the mean difference.

[c] p-value at 95% confidence level; no p-value is statistically significant after the Bonferroni correction for k = 20 (α = 0.0025).

In order to examine any differences in students' attitude in chemistry instrumentation before and after the use of ARiEL, a paired student t-test was performed for each item. Average value of responses and p-value for each item are shown in Table 3. While most items showed no measurable difference, the t-tests for items 1, 4, 5, 18, 19, and 20 had p-values less than 0.05. For all 6 of these items, changes were towards the positive word in the semantic differential item such as easy, simple, clear, safe, relaxed, and secure. However, in order to minimize Type 1 error with multiple hypothesis testing, it is necessary to make an adjustment to the α-value. A posthoc Bonferroni correction[31] was applied, where $\alpha = 0.05$ was divided by 20 to account for the number of items. This process resulted in the corrected α-value of 0.0025 ($k = 20$). No significant difference was detected for all 20 items after the Bonferroni correction, including the 6 items which showed p-value less than 0.05.

Although the difference in mean response values was not significant for individual items with the conservative α-value, further subscale comparisons using paired t-tests with a corrected α-value of 0.0125 reveal some interesting differences between the pre- and post-survey scores. Table 4 shows scores in % for each subscale, calculated for both pre- and post-survey. Notable differences in scores between pre- and post-survey can be seen for the Intellectual Accessibility and Anxiety subscale, even with the adjusted α-value (0.0125). A significant 4% increase in the Intellectual Accessibility score indicates that having ARiEL available helps students feel that instrumentation is more intellectually accessible. While the level of anxiety towards chemistry instrumentation was not as high as the anxiety level towards chemistry as a subject,[24,25] a 6% decrease in the Anxiety subscale score begins to suggest that the use of ARiEL aids in further decreasing students' uneasiness of using instruments.

Table 4. Subscale Scores[a] Measuring Attitude Towards Chemistry Instrumentation and Paired T-test Results for Each Subscale.

	Intellectual Accessibility	Enjoyability	Satisfaction	*Anxiety*
Pre-test Score	48	57	63	43
Post-test Score	52	57	65	37
p-value[b]	0.0074[c]	0.64	0.25	0.0012[c]

[a] Average of the item ratings as a percent of the scale (scale value 1 = 0%, 7 = 100%). Refer to Table 2 for reversed items.
[b] P-value from paired t-test ($\alpha = 0.05$).
[c] Significant after the Bonferroni correction for $k = 4$ ($\alpha = 0.0125$).

Student feedback

At the end of the post-survey, students were encouraged to provide any comments related to the ARiEL system, including suggestions. Students who provided open responses to this question were less than 20%, Nonetheless, the preponderance of comments were positive, and the two most common comments can be paraphrased as students saying that they liked the overall experience and that the app was fun and easy to use. Many students thought that having more interactive features embedded within the app would be valuable in terms of learning and promoting interest. Suggestions included adding a variety of pop up buttons that provide information on different functionalities of the switches on the instruments. Some students also mentioned that ARiEL will be beneficial to many other students, because the system is easy to use, and current generation is very comfortable with using technology. Note that this impression of student digital familiarity may not be universally true[32], but is reported here based on collected student feedback for this stage of development of ARiEL.

IMPLICATIONS, LIMITATIONS AND FUTURE WORK

The overall positive feedback received from students regarding the use of ARiEL suggests that this type of tool is helpful and can be used not only to stimulate students' interest in instrumentation, but it can also be a good learning medium. This observation with general chemistry students mirrors recently published work with AR applications in upper level laboratories.[22] A particularly important piece of information obtained through the modified ASCI is how students' attitudes changed to be less anxious but at the same time to be clearer about learning and using instruments when ARiEL was present as a tool they can access during the laboratory session. As mentioned in student comments, current generation of students are already familiar with advanced technologies. When designed and used efficiently, incorporating such technologies in learning environment could work to promote interest while reducing the tension associated with learning chemistry.

One of the limitations worth noting is the voluntary nature of participation in Phase 2. The students who participated in the entire study – from completing the pre-survey, downloading the app, using the app, and finishing the post-survey – are potentially those who are more willing to explore ways to learn. Because the app requires students to engage in some reading on the webpages, it is difficult to conclude that every student would find this type of tool beneficial. One possible way to improve this limitation, based on the student feedback from the study, is including more interactive features within the application to make it more interesting and attractive. Although the proof-of-concept idea of this project was to provide the immediacy of information to students when they need it the most, it is possible to take advantage of AR technology and include more interactive functions to capture students' attention for future versions of the ARiEL application.

Secondly, the EFA results indicate that a few items on the modified ASCI showed no strong association with one factor. Since two of the four subscales showed significant attitude changes before and after the use of ARiEL, future study will consider revising the instrument version of ASCI used in the Phase 2 study for more clear and accurate measurement of students' attitudes toward chemistry instrumentation.

Perhaps the most notable concern regarding the ARiEL application is the possibility that the use of electronic devices may not be allowed during laboratory periods due to safety issues. One possibility for overcoming this concern is to have dedicated devices available in the laboratory with ARiEL installed, so that the use of ARiEL is not forcing students to expose their personal devices to laboratory chemicals.

Despite the aforementioned limitations of the study, the evidence obtained during the phases 1 and 2 suggest that students are open to utilizing new tools like ARiEL to learn more about chemistry instruments. Because instrumentation involves both fundamental and practical knowledge that can be transferred to many other fields besides chemistry, the potential of promoting learning through ARiEL is promising. General chemistry is a course offered to many, if not all, students in STEM fields, and instruments are widely used in chemistry laboratories.[3,4] Moving students from a "black-box" understanding towards a more holistic view of the role of instruments in the laboratory has the potential to have an important, positive effect on student learning.

CONCLUSION

An application utilizing AR technology was developed to aid in student learning in chemistry laboratory courses. Unity and Vuforia were utilized to develop the application, where two Object Targets were embedded within ARiEL for a proof-of-concept design. The two initial targets, pH meter and conductivity meter, were chosen not only because they are small, benchtop equipment making it easier to work with in early stages of development, but also because they are widely used in general chemistry laboratory courses. The beta version of the application was tested by focus groups of first-term general chemistry students using iOS application testing program, where positive usability results were obtained. A larger scale usability study was carried out in General Chemistry II Laboratory course at a large Midwestern University, where an acceptable usability score was obtained. Paired t-tests of ASCI items indicated that the use of ARiEL not only resulted in less anxiety regarding instrument usage, but also aided in students feeling instrumentation was easier and clearer. Feedback from the participating students from both parts of the study indicated that more interactive functions will be useful and interesting, which can be applied to ARiEL for future stages of the project.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information containing SUS results from the focus group study and the scree plot for the EFA is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX.

[ACS will fill this in.] Example brief descriptions with file formats indicated are shown below; customize for your material.

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ACKNOWLEDGMENTS

This project is funded by National Science Foundation (NSF) Division of Undergraduate Education (Grant #: DUE-1712086). The authors would like to thank all students who participated in the study.

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