Evaluation of Augmented Reality Application Usage and Measuring Students' Attitudes toward Instrumentation

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Abstract

Incorporation of previously reported AR technology (ARiEL) for general chemistry laboratory was attempted for the second time, a replication effort designed to provide students with an option to read about the nature of instruments used in an experiment. Students' app usage was tracked to understand the type and amount of information accessed, and the original Attitudes toward the Subject of Chemistry (ASCI) was modified and validated using confirmatory factor analysis (CFA) to measure students' attitudes toward instrumentation. The results of these assessments indicated that students preferred information directly related to the target experiment, and the amount of time spent accessing information deemed less essential to the task at hand was not substantial. Nevertheless, the modified ASCI measurements suggested positive changes in both cognitive and affective domains of students' attitudes, overall. These results were in agreement with the initial study of ARiEL, implying that an additional system such as ARiEL could be helpful for general chemistry students in making instrumentation more approachable.

Keywords: Laboratory Instruction, First-Year Undergraduate, Conductivity, pH

Introduction

With rapid advancement of technology in the past few decades, countless technologies are now embedded in our lives. In the past decade, technologies that involve virtual experiences have been receiving more attention. Virtual reality (VR) provides users with three-dimensional, computer-generated environments.[1] Augmented reality (AR), a variation of VR, can provide a physical environment overlaid with a computer-generated, informational environment, allowing users to experience both worlds simultaneously.[2]

Technological progression such as this shows the promise in positively impacting classroom environments and teaching methods.[2,3] While museums and libraries used AR before it entered classrooms, AR has been used as a teaching tool or resource for students in higher education courses in the past decade.[3-7] This is especially true in the fields of science, technology, engineering, and mathematics (STEM), such as health science,[8,9] astronomy,[10] and engineering.[11,12] A growing movement in the use of AR has also been noticed in chemistry classrooms and laboratories. In chemistry, many AR-based tools were developed to be used as a virtual laboratory platform for experiments and safety,[13,14] informational platform,[15-18] and as a visualization tool.[19-23] Additional reports of using AR to increase cooperative learning environment are also available.[24,25]

The incorporation of AR in science learning environments can present multiple benefits for students and teachers. For instance, AR can provide a simulation of various situations, exposing students to the scenario without the use of potentially dangerous materials.[26] Another example of utility is an AR titration tool, where students can experience the titration experiment prior to interacting with chemicals through the AR application.[13] Aid in molecular 3D visualization is another commonly studied application of AR rendering technology. This application has been found to help students understand various aspects of chemistry[19,20,22] such as stereochemistry,[27,28] and also increase their spatial reasoning ability.[28] In other cases, AR with marker-based targets can be used to simply link information to objects, including scientific instruments.[4] For example, Naese et al. utilized a marker-based AR application to provide information on components of analytical chemistry instruments for students in the upper-level chemistry laboratory course.[16]

This communication follows up a previous study of an application called Augmented Reality in Educational Laboratory (ARiEL)[15] moving beyond marker-based target AR in the teaching laboratory. The information included in the ARiEL application involved an accompanying suite of web sites that provide (a) an introduction to what the instruments measure and how they measure the variables (b) operational instructions in a form of list and video (c) a brief introduction to calibration, and (d) a short note on safety. As part of the pedagogical implementation, the previous work measured student attitudes with a modified version of the Attitude toward the Subject of Chemistry Inventory (ASCIv1)[29] and found positive reception of the AR application.

The current study is both a replication and an extension of the initial ARiEL study,[15] and it is based on two objectives. First, to understand the extent of the app utilization by tracking how students interact with the information through the interface. This tracking was accomplished using Google Analytics, which allowed identification of landing pages accessed through the app and the subsequent flow of the accompanying website by the users. This tracking process allows the identification of the most sought-after information by the students, as well as to gauge the extent of information accessed. Additionally, the suite of webpages linked to the ARiEL application were updated to include an additional page with a brief history of instrument development and their real-world applications beyond the teaching labs experiments students were completing. These new pages were designed to allow student exploration of information not directly related to the experiment at hand, thereby gauging any level of interest in learning about the instruments themselves.

Secondly, the study aims to validate the factor structure of a modified ASCI for measuring students' attitudes toward chemistry instrumentation, creating a new survey to quickly assess attitudes about scientific instruments and measurement through a series of semantic differential scales. The importance of assessing the affective domain to understand meaningful learning arises from a need to determine engagement of three domains: cognitive, affective, and psychomotor ("doing").[30,31] Laboratory courses are inherently centered around psychomotor domain,[32] and while cognitive and affective domain-centered research studies toward chemistry have been prevalent,[29,33-41] fewer studies have examined laboratory learning in relation to affective domain.[32,42-46] Moreover, characterizing and understanding students' affective states towards specific areas of laboratory learning, such as instrumentation, is uncommon. Therefore, this study seeks to build upon the initial ARiEL study by replicating the attitude measurement toward chemistry instrumentation.

Methods

Course-wide Implementation and Data Collection

The study procedure was approved by the Institutional Review Board (IRB) as an exempt study. Detailed description of the methods used for the course-wide implementation of the ARiEL application is provided in the Supporting Information (SI).

The ARiEL application in this study was linked to the same page suite as the initial study,[15] but an additional page was added for both the pH meter and conductivity meter. This new webpage was allowed students to access information about history and importance of the instruments being used in the general chemistry lab course. This new information in the webpages was not required to accomplish the laboratory and is thus most likely to be associated with curiosity driven interest.

Two other minor usability updates were made as illustrated in Figure 1 which shows the added instrument history and usage pages accessible via a link button labeled "How does this instrument work".

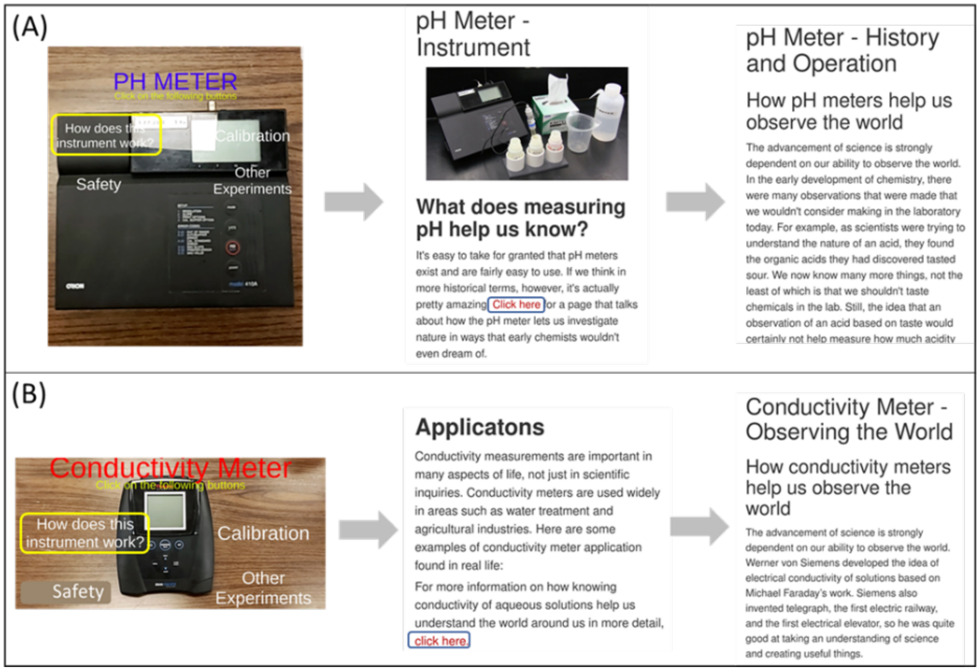

Figure 1. Screenshots of ARiEL screens where (A) depicts a portrait mode with the pH meter, and (B) illustrates a landscape mode with the conductivity meter. Information shown in these screenshots is not a complete representation of the information present on the webpages.

Data Analysis

Students used the ARiEL interface in the laboratory course associated with second semester General Chemistry. A pre-/post- administration of a survey was completed related to ARiEL and its usability along with the modified ASCI. A data cleanup process was used to build the dataset from raw data and is described in the Supporting Information. Most notably for 111 students who completed both phases matching of student responses for pre-/post- analysis was carried out.

A confirmatory factor analysis (CFA) was performed using the larger dataset from the pre-survey responses (n = 280) as paired responses were not required to investigate the factor structure of the instrument. While *t*-tests were performed using both paired (n = 111, parametric) and unpaired (non-parametric) responses, only non-parametric results are reported as no statistical differences were found between the paired and unpaired sample groups.

Google Analytics data were analyzed only for the days and times at which the target experiment was taking place in the teaching laboratory. Google Analytics records usage anonymously so the researchers cannot trace the website uses to any individual participants. Patterns of usage were examined, such as which page students chose to visit first from ARiEL, number of drop-offs (the number of students who discontinued the website usage), the average duration of website usage, and the user flow through the suite of pages associated with ARiEL.

All statistical analyses were completed using R/RStudio. Detailed information on statistical analyses, including the definition of the acronyms used in CFA, are included in the Supporting Information. The usability measures using system usability scale[47] are also available in the Supporting Information.

Results and Discussion

Google Analytics

The first week of the study recorded a frequency of 113 for webpage landing. The second week only recorded 9 webpage uses, indicating that students who used the application during the first week most likely chose not to use it again in the second week. This drop in the usage in the second week suggests that the novelty of the application may have provided initial motivation for many students to try it out. In the first week of the experiment, the most frequently chosen webpage, where approximately 31% of the total traffic started with, was the *Calibration* page for the pH meter as shown in Table 1. A portion of the target experiment was to calibrate each instrument. Thus, this observation is not particularly surprising as it suggests that students were drawn to information most closely related to their task at hand.

Table 1. The most frequently visited webpages through the ARiEL app during the first week of the app implementation in General Chemistry II laboratory.

	Page	Percent (%)
1	Calibration – pH meter	31.0
2	Instrument – pH meter	30.1
3	Calibration – Conductivity meter	17.7
4	Instrument – Conductivity meter	15.0
5	Other (pH meter / Conductivity meter Experiments, Safety)	6.3

Second most visited page was the *Instrument* page for the pH meter, which was linked to the "How does this instrument work" button in ARiEL. The frequency at which students visited this page as a starting point was nearly 30% of the total webpage usage. Based on this observation, it appears that some students were seeking to learn how the pH meter operates. The conductivity meter *Calibration* page was the third most frequently recorded landing page (.17.7%), and the conductivity meter *Instrument* page followed behind closely at 15%. The remaining 6.3% consisted of a few occasions where students chose to visit pages such as *Experiments* or *Safety* first through the application.

The drop-off rate after the initial arrival to the webpage through ARiEL was approximately 83%. It is important to note that students were accessing this information while they were in the laboratory itself, and therefore had prescribed tasks to complete. In addition, students were not required to read the information they accessed through the app to be able to complete their experiment. Thus the observed high drop-off rate could mean either (a) students were content with the information they found on the landing page for the purpose of the activity and turned their attention to the practical tasks at hand, or (b) students were not sufficiently interested in other information to invest the time to read it. The subsequent drop-off rate through the 1^{st}, 2^{nd}, and 3^{rd}

interactions was nearly 70% on average, indicating that majority of students exited the webpage after each interaction. The idea that the ARiEL interface provides rapid access to practical information is consistent with this observation. In addition, engagement with the suite of ARiEL sites is likely to match other web sites people visit without required information gathering, and interactions are mitigated by impressions formed in seconds.[48] Thus, it is not surprising that even if there was some interest generated in the first week, that students did not engage with the application in the second week, as the inclination towards practical motivations for students in the laboratory has been previously observed.[46]

In addition, an extra page was included within the *Instrument* page for both pH and conductivity in this study. This addition was designed to assess whether web-site design could influence the ability to have students willing to read through extra information about measurement, beyond the readily accessible information and more practical information directly accessed via ARiEL. Unfortunately, based on the Google Analytics data, the additional page with history, importance, and real-life applications was not accessed by any students while they were working in the teaching laboratory. This observation, while discouraging, suggests the importance of tailoring technology to immediate student needs. In the case of ARiEL and student behavior in the teaching laboratory setting, the need to "finish" the lab establishes time constraints for students, even for labs that are not using the entire allocated time for the class.[46] Considering the previously reported student goals in laboratory courses and the Google Analytics observations made in this study, an interest in having students engage with how instrumentation fits with scientific discovery likely needs to be formally part of the course content in order to inspire student attention to the topic.

ASCI Factor Analysis

Exploratory factor analysis (EFA) in the previously reported study[15] revealed a 4-factor, 16-item model, as shown in Table S1 of Supporting Information. The extracted factors were Intellectual Accessibility (IA, 4 items), Enjoyability (5 items), Satisfaction (3 items), and Anxiety (4 items). Confirmatory factor analysis (CFA) was carried out using current data to test structures of the ASCI measuring students' attitudes toward chemistry instrumentation (see Supporting Information for details of this analysis). In addition to this model, several additional possible variations were investigated. Table 2 includes a list of all structural models along with their CFA results. The 4-factor model (Model 1) resulted in an inadequate fit (CFI = 0.853, RMSEA = 0.098, SRMR = 0.088).

Table 2. List of CFA models and the corresponding fit indices.

Model[a]		Fit Indices[b]		
		CFI	**RMSEA**	**SRMR**
1	*4-factor, 16 items:* IA Anxiety Enjoyability Satisfaction	0.853	0.098	0.088
2	*2-factor, 8 items:* IA Anxiety	0.944	0.097	0.057
3	*2-factor, 7 items:* IA Anxiety (w/o Item 14)	0.964	0.088	0.047
4	*2-factor, 7 items:* IA (w/o Item 4) Anxiety	0.959	0.085	0.044
5	*2-factor, 6 items:* IA (w/o Item 4) Anxiety (w/o Item 14)	0.993	0.039	0.026

[a] "IA" refers to the Intellectual Accessibility factor.

[b] Thresholds utilized in this study: CFI > 0.95; RMSEA < 0.06; RMSEA < 0.06. Please refer to SI for more information about the fit indices.

While the 4-factor model (Model 1) did not result in adequate fit indices, this was not unexpected considering the difficulties ASCIv1 for chemistry, as opposed to chemistry instrumentation, has faced in previous studies.[29,33] For example, the ASCIv1 initially showed a 3-factor model with two extra sets of subscales consisted of low-loading items and a single item.[29] In a study that attempted to replicate the ASCIv1 factor structure, multiple cross-loading tendencies of some items were observed. This structural validation difficulty of the ASCIv1 led to the development of a reduced, 2-factor instrument (ASCIv2).[33]

Based on the previous factoring characteristics of the ASCIv1 as well as the subscale results showing significant differences before and after the usage of ARiEL in the initial study,[15] CFA was performed using a 2-factor, 8-item model that consisted of Intellectual Accessibility (IA) and Anxiety subscales (Model 2). As can be seen in Table 2, improved CFI (0.944) and SRMR (0.057) values were observed, while a high RMSEA value (0.097) was still evident.

A scale modification process was undertaken to build a shortened version of ASCI that measures students' attitudes toward instrumentation (see Supporting Information). After examining EFA structure (Table S3, SI) and modification indices (MIs), a series of CFA analysis was carried out by removing item 14 (Model 3), then item 4 (Model 4), and finally, both items (Model 5). As Table 2 shows, eliminating either item 4 or 14 improved the CFI and SRMR values, but the RMSEA values remained above the acceptable threshold. However, removing both items (Model 5) yielded the best fit indices (CFI = 0.993, RMSEA = 0.039, SRMR = 0.026).

While post-hoc model revision based on MIs is not uncommon, modification of the scale should always be theoretically supported.[49,50] Though removing one item from each subscale resulted in an acceptable model fit, the reason behind observation based on the items themselves was not clear. For instance, items 1, 4, 5, and 10 all appeared to describe a logical view of difficulty associated with instrumentation, suitable for Intellectual Accessibility subscale. Likewise, items 14, 18, 19, and 20 seemed to be describing a level of concern (or lack thereof) toward instrumentation. As an extra validation step to assess any difference between the Model 2 and Model 5, the subscale scores from the pre- and post-surveys were compared for the two models. Table 3 shows the subscale scores of Models 2 and 5, along with the Welch's two sample *t*-test results between the two models. As the *p*-values indicate, no statistically significant difference was seen in either subscale scores, and this observation was valid for both pre- and post-surveys. These results suggest that the two models, with and without items 4 and 14, do not show any difference for the latent variables that the factor structure suggests are measured by the survey. Although it was difficult to understand the reason behind the poor behaviors of items 4 and 14 in Model 2 simply based on the polar adjectives, the overall ideas measured by each subscale were unaffected by the absence of those items. Consequently, the scale structure of Model 5 can be used as a modified ASCI measuring students' attitudes toward chemistry instrumentation. The reliability of each subscale was assessed by calculating McDonald's omega (ω), and details about the results can be found in the Supporting Information. In short, both subscales exhibited acceptable internal consistency.

Table 3. Comparison of subscale scores[a] between models 2 and 5[b], and comparison of pre- and post-survey scores within model 5.

	Model 2		**Model 5**		**Inter-model Welch's *t*-test *p*-value**[c]	
	IA	**Anxiety**	**IA**	**Anxiety**	**IA**	**Anxiety**
Pre	49.0	43.1	49.5	42.9	0.7612	0.8849
Post	54.8	38.0	54.6	37.6	0.9193	0.8358
p-value[d] from Welch's *t*-test between pre- and post- surveys for Model 5			0.008451	0.004936		

[a] Scores represented in % (i.e., 1 = 0%, 7 = 100%).
[b] Refer to Tables 2 and 3 for the items in each model.
[c] No statistical significance was detected for the inter-group comparisons.
[d] Both are significant after the Bonferroni correction for k = 2 (α=0.025).

Results of ASCI Model for Student Responses

The pre-survey score of the Intellectual Accessibility subscale was 49.5% (Table 3), showing that students felt instrumentation was neither particularly difficult nor straightforward before the target experiment. The post-test score showed a 5.1% increase, which was a significant change (p-value < 0.01), indicating that their feelings toward instrumentation shifted positively with the use and availability of ARiEL. Comparing this work on instrumentation with previous finding about "chemistry" itself, the subscale score of 49.5% toward chemistry instrumentation in this study was substantially higher than that of 31.8% reported in the previous study of students' attitudes toward chemistry as a subject,[33] where the Intellectual Accessibility subscale was composed of the same items including item 4. While noting there is substantial uncertainty about comparability of student samples, it appears that at least for the population of students in the current and previous studies,[15] a modest, but more favorable view of instrumentation is present at the outset than of chemistry as a subject.[33] This observation might be connected to students connecting instrumentation to technology, but such concepts are speculation in the context of how this survey instrument is constructed.

Similar results were true about the Anxiety subscale, where the pre-survey score of 42.9% decreased substantially by 5.3% after the target experiment with ARiEL. Judging by the pre-survey score of 42.9%, second-semester general chemistry students were not highly anxious about using instruments in the laboratory. A qualitative interview study exploring students' feelings in chemistry laboratory reported that students chose words such as *Nervous* and *Anxious* less frequently than they did words like *Interested* when describing their experiences in laboratory.[42] In general, the level of anxiety students possess in laboratory seems to be roughly in line with their anxiety towards instrumentation. In any case, the observed decrease in Anxiety subscale score may suggest a positive effect ARiEL made on students' affective domain of learning, although the ability to deconvolute the role of ARiEL and the experiments themselves is limited in this study.

Another noteworthy outcome in this study is that the ASCI results were consistent with those of the initial ARiEL study conducted in Spring 2019 semester, suggesting this replication of the previous study largely supports the prior observations and conclusions. For example, Table S4 in Supporting Information shows a side-by-side comparison of the subscale (IA and Anxiety) scores from the current study and the initial report. In the initial study,[15] IA score changed from 48% (pre-survey) to 52% (post-survey), whereas the score shifted from 49.5% to 54.6% in the current work, showing that both changes were positive and significant. Similarly, the Anxiety subscale scores started at 43% for both studies, and they decreased to 37% and 37.6% for the initial and the current study, respectively. Once again, the results from both studies suggest the laboratory experience, including the availability of ARiEL leads to positive effects on students' level of anxiety toward instrumentation. While the 4-factor, 16-item model of the ASCI measuring students' attitudes toward chemistry instrumentation could not be validated in this study, the two retained factors in the shortened-version factored reliably when compared to the initial study. The 6-item ASCI could be used to understand both cognitive and affective components of attitudes toward chemistry instrumentation in the future.

Conclusion

The work presented here was both a replication and extension of the initial report of ARiEL, with the addition of the pattern of students' app usage being evaluated through the web traffic data. In addition, the ASCIv1 was further modified to be related to chemistry instrumentation and validated using CFA. This modified model for analysis with this ASCI instrument consisted of 2 factors and 6 items, and the new scale was utilized to analyze students' attitudes toward chemistry instruments for the second time. The modified ASCI results in the current work mirrored those of the initial study, confirming the use of AR technology such as ARiEL is capable of supporting gains in both cognitive and affective domains of attitude for students.

Based on the Google Analytics data obtained from the study, the level of reading students engaged in through the ARiEL application appeared to be modest. In addition, students did not access an additional page with no direct ARiEL interface link that provided information about the history and importance of instruments. By contrast, the most visited pages through ARiEL were those directly related to the practicalities of the experiment being conducted. The overall results from the initial and current ARiEL studies collectively point at the potential usefulness of practically oriented AR interfaces to some students, as well as its contributions to potential benefits on students' attitudes. The modest engagement with web pages related to the applications of instrumentation in laboratory courses suggests further curricular changes are likely needed to provide materials related to instrumentation that students find interesting and meaningful.

Associated Content

Supporting Information

The Supporting Information containing information related to (1) data collection and cleaning; (2) analysis of Google analytics data; (3) usability studies and (4) further discussion about limitations and implications of the study is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX.

An_Holme_SI (.docx)

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