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## Investigating students' affective states toward laboratory and context-based chemistry

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# Investigating students' affective states toward laboratory and context-based chemistry

by

**Jiwoo An**

A dissertation submitted to the graduate faculty  
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Chemistry (Chemistry Education)

Program of Study Committee:  
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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this dissertation. The Graduate College will ensure this dissertation is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University

Ames, Iowa

2020

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## ABSTRACT

Observations of natural phenomena are made possible with the invention of scientific apparatus and instruments. The focus in science education, however, has primarily been on theories rather than what enables the development of such theories, and chemistry curricula reflect this tradition. Introducing students to the role of instruments in science, both in experimental and theoretical aspects, can improve students' overall understanding of, and appreciation for scientific practices. In addition, students' increased perception of how chemical concepts are developed and how scientific observations are made can advance their awareness of the nature of science, thereby improving scientific literacy. Integrating the idea that instruments hold a central role in scientific progression can be achieved in both laboratories and lectures, providing students with opportunities to connect concepts to history, scientific practices, and applications. This dissertation is comprised of a series of studies which explores the use of technology and context-based curricular approach to provide general chemistry students with more information about instruments and applications in chemistry. Based on constructivism and the theory of meaningful learning, the affective learning domain, such as attitudes and motivation, was assessed in both chemistry laboratory and lecture courses. An augmented reality tool designed to connect students to information about commonly used instruments in a general chemistry lab course, specifically a pH meter and conductivity meter, was developed, implemented, and its effects on student learning and attitudes were investigated. In addition, for a chemistry lecture course, a context-based curricular approach was taken to introduce students to chemical concepts related to real-life applications, as well as to the role of scientific instruments, and this effort was assessed.

## CHAPTER 1

### GENERAL INTRODUCTION

#### 1.1 Introduction to chemistry laboratory learning

Chemistry education without laboratory work is difficult to imagine. Laboratory work has existed since the 19<sup>th</sup> century,<sup>1,2</sup> at which time it was considered as an educational revolution.<sup>2,3</sup> In the early years, laboratory activities served as an opportunity where students could confirm what was taught by teachers.<sup>2</sup> However, science educators began looking at laboratory education with a different perspective in the 1960s. It was a place with a chance to take part in the process of inquiry,<sup>4</sup> increase problem-solving skills, and encourage students to understand the nature of science.<sup>5</sup>

Many goals for laboratory instruction in science education were recognized long ago, and a few are listed here: to stimulate and maintain interest and curiosity in science, promote scientific thinking, encourage recognition of scientific knowledge and the tentative nature of scientific theories and models.<sup>6,7</sup> More recent goals include helping students form scientific habits of mind and understand the nature of science.<sup>8</sup> Even though the potential benefits of laboratory education had been identified, the lack of beneficial evidence led some educators in the 1970s and 1980s to begin questioning the effectiveness of the laboratory work.<sup>8</sup> Unfortunately, this discussion continues after nearly 50 years.<sup>9,10</sup>

Lunetta and Tamir's checklist listed four phases of laboratory activity necessary to accomplish the identified goals of laboratory education. These phases were planning and design, performance, analysis and interpretation, and application.<sup>11</sup> In 1979, these authors identified that students are most commonly instructed to make measurements, record observations, and draw conclusions from experimental results. With minimum opportunities to hypothesize, design

experiments, or discuss errors, they argued that students were working as “technicians” in laboratory courses.<sup>11</sup> The number of publications of innovative experiments and laboratory pedagogies<sup>12,13</sup> reflect the various efforts made by chemistry education researchers<sup>9</sup> to improve students’ laboratory experiences. However, laboratory structures of many higher education systems remain unchanged, employing cookbook style instructions as identified in 1979.<sup>11</sup> While challenges of course size, time, and resources are valid, it is clear that successful laboratory instruction requires changes in current methods.

## 1.2 Instruments in chemistry and chemistry education

Scientific instruments stand at the center of chemistry, from the era of alchemy to today. In education, however, the traditional emphasis put on theory of chemistry has overshadowed the role of instruments in scientific progress in chemical analysis.<sup>14</sup> Baird’s statement, “Instruments are not in the intellectual basement; they occupy the same floor as our greatest theoretical contributions to understand the world”, provides an insight that instruments hold an equal amount of importance as do theories in helping us understand our world.<sup>15</sup> We all know the states of matter are largely divided into three categories: solids, liquids, and gases. However, study of gases was only achievable by the invention of various tools such as pneumatic trough and eudiometers in the 18th century.<sup>16</sup> Before then, gases were thought of as spirits or simply as “air” due to their invisible characteristics.<sup>17</sup> Understanding the concept of gases as we know it now, would have been nearly impossible without the development of scientific instruments. It was from this combination of chemical thinking and data that Antoine Lavoisier was able to disprove the phlogiston theory. Another example of chemical revolution starts with the invention of mass spectrograph by Francis Aston, which enabled detection of isotopes.<sup>18</sup> Now the



application of mass spectrometry in modern chemistry extends from academic research to numerous areas such as medical, environmental, and pharmaceutical industries.

As demonstrated by these examples, instruments are linked to chemical history, theories, and applications. One important aspect of the nature of science (NOS) connotes that science is empirically based, meaning observations of natural phenomena are made with and filtered through instruments.<sup>19</sup> The stories of gases and isotopes are obvious examples of the empirical nature of science: observation of invisible substances was made possible by using instruments, which led to a development of new chemical theories. They not only validate the imperative roles instruments held in scientific advancement, but they also show the interrelations among the history, theories, and instruments. Despite the apparent significance instruments hold in science, it is uncommon to find a chemistry curriculum, especially that of general chemistry, that incorporates the role of instruments in scientific concepts.

### **1.3 Affective learning domain**

Turning more towards learning, the idea of constructivism was first introduced by Jean Piaget in 1936.<sup>20</sup> According to constructivism, knowledge is constructed by a learner as they attempt to organize the existing structure and modify it with new information.<sup>21</sup> Novak's Human Constructivism adapted the constructivism into the field of education, stating that education should empower learner's construction of knowledge.<sup>22,23</sup> The integration of new knowledge into existing knowledge structure, referred to as meaningful learning, occurs when students are engaged in three domains of learning: cognitive (thinking), psychomotor (doing), and affective (feeling).<sup>22</sup>

While all three domains are essential to achieve meaningful learning, there has been a surge of studies focusing on the affective domain of learning. In chemistry education research, over 90 articles reported in the past two decades have specifically studied affective aspects such as students' attitudes, self-efficacy, self-concept, expectations, and motivation.<sup>24</sup> The reason for this attention comes from the influence emotions have on human behaviors, ultimately determining how people learn.<sup>25</sup> How students feel in chemistry courses have been linked to their performance, as well as their decisions to engage or not to engage in learning.<sup>26-30</sup>

Though many studies have focused on assessing affective learning aspects in chemistry education, work focusing on affective domain toward instruments are difficult to find. A series of studies presented in this dissertation is an attempt to contribute to the field chemistry education research by evaluating general chemistry students' attitudes and motivation, specifically toward instrumentation, as well as their affective states in courses utilizing technology and contexts-based instructional method to incorporate the role of instruments in chemistry.

#### **1.4 Organization of the dissertation**

This dissertation includes a series of studies conducted with two overarching research interests: (1) assessing general chemistry students' motivation and attitudes toward instrumentation and chemistry learning influenced by technological tool and systems thinking instructional approach, and (2) understanding how general chemistry students conceptualize scientific instruments. The present dissertation is organized as following:

**Chapter 2** describes the first attempt at creating augmented reality application (ARiEL) targeting instrument learning for general chemistry students. The developed application was implemented in the second-term general chemistry laboratory course, where positive changes in

students' attitudes towards instrumentation were observed using the modified version of the Attitude toward the Subject of Chemistry Inventory (ASCI).<sup>31</sup> With the availability of ARiEL application, students' anxiety towards instrumentation decreased and their perceived intellectual accessibility increased. In addition, the usability score of the application, measured by system usability scale (SUS), showed suitable level of user-friendliness.

**Chapter 3** describes a replication study, where a second attempt at implementing ARiEL in the second-term general chemistry laboratory course. This study specifically investigated what information students accessed through the ARiEL app and the pattern of usage. In addition, a shortened, modified version of the ASCI was validated to measure students' attitudes toward chemistry instrumentation. The results showed that students preferred to access information most relevant to the target experiment, rather than the extra information related to instruments' history and importance. Nonetheless, positive effects of ARiEL on students' levels of anxiety and intellectual accessibility towards instrumentation were seen again, indicating the potential usefulness of ARiEL as an additional resource for laboratory courses.

**Chapter 4** describes a mixed-methods research study exploring the current general chemistry students' conceptualization of scientific instruments. A survey was written and distributed to acquire a snapshot of the understanding students had regarding the role of instruments in and outside of science, data evaluation, as well as their affective states towards instrument learning. The interview study revealed that majority of students possessed shallow understanding of the central role instruments have in science, lacking the idea of nature of science (NOS) and that relevancy to life greatly influences students' motivation to learn about instruments.

**Chapter 5** describes an investigation of how the employment of systems thinking curricular approach affects general chemistry students' affective learning domains. Four types of

motivation: intrinsic, identified regulation, external regulation, and amotivation, were assessed with Situational Motivation Scale (SIMS)<sup>32</sup> in relation to student's final exam scores (ACS exam). Intrinsic motivation and external regulation were positively correlated with the final exam scores, whereas amotivation was negatively correlated with the exam scores. Students' attitudes, as measured by the second version of the Attitudes toward the Subject of Chemistry (ASCIv2),<sup>33</sup> were also significant predictors of performance on the ACS exam. Overall, this study failed to observe any particular positive impact the incorporation of the systems thinking contexts made on students' motivation and attitudes perhaps indicating that more explicit instructions and varying systems thinking topics may be needed to realize the hypothesized value of adding rich context in the teaching of chemistry.

**Chapter 6** provides a brief summary of the presented research studies.

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**CHAPTER 2****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 toward 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, the 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 toward chemistry instrumentation. The results suggest that the availability of ARiEL helps to reduce anxiety associated with using instruments and to improve intellectual accessibility.

## 2.1 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.<sup>1-4</sup> Laboratory courses have always been considered to be important, and many educators have argued that laboratory must be an integral part of science education.<sup>3-6</sup> Despite these widely held beliefs, some researchers suggest that there is no concrete evidence supporting the beneficial nature of laboratory courses.<sup>3,7</sup> 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.<sup>8,9</sup> 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.<sup>9</sup> 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.<sup>10</sup> 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 the general chemistry laboratory to improve students' understanding of experimental procedures.<sup>11</sup> On the basis of 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,<sup>12</sup> to create an interactive, collaborative learning environment,<sup>13</sup> to help students learn about machinery operation,<sup>14</sup> and to function as an interactive experimental manual.<sup>15</sup> 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 a 2-D format,<sup>16,17</sup> 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.<sup>18</sup> 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.<sup>19</sup> 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 analog resources.<sup>19</sup> 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 nontraditional method to attract students' attention.<sup>20</sup> 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.<sup>21</sup> In this study, they found a significant improvement in students' understanding of chemistry experiment concepts using the developed tool.<sup>21</sup> 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.<sup>22</sup> 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 an AR tool.<sup>22</sup>

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 allow scientists to make measurements of nature that would otherwise be unobserved, they are often overlooked in many science courses,<sup>23</sup> 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 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 toward chemistry instrumentation. Initial instruments that were chosen for the development of this application were the 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.

## **2.2 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 (3-D) objects. The image registration capability allows the developer to position and orient virtual objects, such as 3-D models and media, in relation to the real-world object viewed through the camera of a 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 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 and rigid, and used 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 the 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#) were 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 Web site containing appropriate information about the instrument. The title and buttons appear as a screen-space overlay on the camera generating the 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 2.1 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, the “Experiments” button is connected to files of experimental manuals that they would be able to perform with each instrument.



**Figure 2.1.** 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 the Apple Developer Program was necessary to work with any iOS devices, whether it is for beta testing or uploading the application to the 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 the 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 min 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.

**Table 2.1.** Initial Discussion Questions for Focus Group Study.

<i>Question</i>
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)

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 10 min with versions of both the pH meter and the conductivity meter. They were also encouraged to look through the information presented on the associated Web sites 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 2.1. 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)<sup>26</sup> based on their experience (Table A1).

### *Phase 2: Class-Scale Implementation.*

This study was based on voluntary participation and was approved by the Institutional Review Board prior to the experiment (Appendix E). In the Spring 2019 semester, ARiEL was implemented in a course for the first time. The General Chemistry II Laboratory course was selected for the implementation study because the course utilizes both the 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 is 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,



laboratories 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 presurvey before the experiment, download the application, and complete a postsurvey after the experiment. Links to the app downloading pages as well as the downloading instructions were provided to the students with the presurvey. Pre- and postsurvey 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.

Presurvey consisted of 4 demographic questions (student ID, sex, major, and number of chemistry courses taken) followed by the modified version of the Attitude toward Subject of Chemistry Inventory (ASCI).<sup>24</sup> In the postsurvey, students were asked to rate the difficulty of the app downloading experience and to indicate the operating system (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 toward chemistry using 20 semantic differential items. In this study, the aim was to find students' general attitudes about working with instruments in the chemistry laboratory rather than the chemistry subject. Xu and Lewis created ASCI (V2),<sup>25</sup> 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 those of the original version.

### 2.3 Data Analysis

Approximately 400 responses were recorded for the presurvey and 300 for the postsurvey, 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 a 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.<sup>26</sup> The survey contains 5 positively worded questions and 5 negatively worded questions, and it utilizes a 5-point Likert scale. The SUS scoring rubric<sup>26</sup> 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.<sup>27</sup> Skewness and kurtosis were determined for each item of the ASCI (pre- and postsurvey), 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 the oblique rotation method was employed. In order to determine the appropriate number of factors to extract, a scree plot was constructed (Figure A1). Upon testing three to five factor extractions, four factors were extracted following the previously published reports.<sup>24,25</sup> On the basis of the EFA results, internal consistency was measured by calculating Cronbach's  $\alpha$  of each subscale. Scores of each subscale in percentage were calculated according to the literature,<sup>24</sup> 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' attitudes toward chemistry instrumentation after being introduced to ARiEL system.

## 2.4 Results and Discussion

### Focus Group Study

The first question (Table 2.1) was asked to understand the degree of preparation that students engage in before each experiment, as preparation is an essential part in laboratory

learning.<sup>8</sup> All students agreed on their method of preparation to be reading the written manual, rewriting the procedure, and completing the 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 10 min, 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 2.1) was whether they would choose a generic search engine or ARiEL when they desire to know more information about instruments during experiments. Of the participating students, 11 out of 12 expressed that they would much prefer ARiEL over a search engine for one or more reasons, and the reasons were as follows: (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) 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 the ability 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.<sup>28,29</sup>

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 2.1), all students answered that the importance is highly ranked. Students agreed that the reason for such importance is because the possibilities of transferring the knowledge to their own fields of interest are high. It was also mentioned that instruments enable them to complete experiments, and that knowing how to use instruments correctly is of significant importance in carrying out experiments in the right way.

The usability aspect of the application was measured by the SUS questionnaire.<sup>26</sup> The SUS items and the median values obtained in the focus group study are shown in Table A1 of Appendix A. 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 the scoring scheme resulted in an average usability score of 88.75, which is comfortably higher than the SUS score of 70 that is indicative of acceptable usability.<sup>30</sup>

## Implementation Study

### *App Downloading*

The app was available as a beta version for two operating systems (OSs), 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 the 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 the ARiEL app. Nevertheless, over 60% of the participating students indicated an 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 value, 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 on the basis of extensive user feedback.<sup>30</sup> 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 nonlaboratory 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 that 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 of ARiEL 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 by 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),<sup>24</sup> 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 the “Emotional Satisfaction” subset, as these items had low loading values toward 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.<sup>25</sup> 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 toward other extracted factors.

EFA results on the Chemistry Instrumentation version of the ASCI from phase 2 are shown in Table 2.2, and item mean scores are shown in Table 2.3. 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.<sup>24</sup> Mean scores for these items from the pre-survey 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. The 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 about 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 2.3. 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.

**Table 2.2.** Exploratory Factor Analysis Item Loadings for ASCI (V1) Measuring Attitude Towards Chemistry Instrumentation.

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

<sup>a</sup> EFA with maximum likelihood method and oblique rotation.

\* = scales reversed when averaging the score.

To examine the internal consistency of the extracted factors, Cronbach's  $\alpha$  value for each of the 4 subscales was calculated. Cronbach's  $\alpha$  values were found to be 0.83 for Intellectual Accessibility, 0.80 for Enjoyability, 0.78 for Satisfaction, and 0.73 for the 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 toward 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 toward 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.

In order to examine any differences in students' attitude toward 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 2.3. 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 toward 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  $\alpha$ -value. A post-hoc Bonferroni correction<sup>31</sup> was applied, where  $\alpha = 0.05$  was divided by 20 to account for the number of items. This process resulted in the corrected  $\alpha$ -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 a *p*-value less than 0.05.

**Table 2.3.** Average Values of Responses for Each Question from Pre- and Post-survey, Mean Difference, and *p*-values.

Item <sup>a</sup>	Polar Adjectives		Response Mean		$\mu_d$   <sup>b</sup>	<i>p</i> -value <sup>c</sup>
			Pre-survey	Post-survey		
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

<sup>a</sup> Items were not reversed for this analysis.

<sup>b</sup> Absolute value of the mean difference.

<sup>c</sup> *p*-value at 95% confidence level; no *p*-value is statistically significant after the Bonferroni correction for  $k = 20$  ( $\alpha = 0.0025$ ).

**Table 2.4.** Subscale Scores<sup>a</sup> Measuring Attitude Towards Chemistry Instrumentation and Paired T-test Results for Each Subscale.

	<i>Intellectual Accessibility</i>	Enjoyability	Satisfaction	<i>Anxiety</i>
Pre-test Score	48	57	63	43
Post-test Score	52	57	65	37
<i>p</i> -value <sup>b</sup>	0.0074 <sup>c</sup>	0.64	0.25	0.0012 <sup>c</sup>

<sup>a</sup> Average of the item ratings as a percent of the scale (scale value 1 = 0%, 7 = 100%). Refer to Table 2.2 for reversed items.

<sup>b</sup> *p*-value from paired t-test ( $\alpha = 0.05$ ).

<sup>c</sup> Significant after the Bonferroni correction for  $k = 4$  ( $\alpha = 0.0125$ ).

Although the difference in mean response values was not significant for individual items with the conservative  $\alpha$ -value, further subscale comparisons using paired t tests with a corrected  $\alpha$ -value of 0.0125 reveal some interesting differences between the pre- and postsurvey scores. Table 2.4 shows scores in percent for each subscale, calculated for both pre- and postsurvey. Notable differences in scores between pre- and postsurvey can be seen for the Intellectual Accessibility and Anxiety subscale, even with the adjusted  $\alpha$ -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 toward chemistry instrumentation was not as high as the anxiety level toward chemistry as a subject,<sup>24,25</sup> a 6% decrease in the Anxiety subscale score begins to suggest that the use of ARiEL aids in further decreasing students' uneasiness in using instruments.

#### *Student Feedback*

At the end of the postsurvey, 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 was 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 the current generation is very comfortable with using technology. Note that this

impression of student digital familiarity may not be universally true,<sup>32</sup> but the report here is based on collected student feedback for this stage of development of ARiEL.

## 2.5. 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 also as a good learning medium. This observation with general chemistry students mirrors recently published work with AR applications in upper level laboratories.<sup>22</sup> 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, the current generation of students is already familiar with advanced technologies. When designed and used efficiently, incorporating such technologies in the 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, including completing the presurvey, downloading the app, using the app, and finishing the postsurvey, 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, on the basis of 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.

Second, 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 a 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 phases 1 and 2 suggests 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.<sup>3,4</sup> Moving students from a "black-box" understanding toward a more holistic view of the role of instruments in the laboratory has the potential to have an important, positive effect on student learning.

## 2.6 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 pieces of 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 an iOS application testing program, where positive usability results were obtained. A larger scale usability study was carried out in the 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.

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## CHAPTER 3

### 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 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 less practical information 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 recourse such as ARiEL could be helpful for general chemistry students in making instrumentation more approachable.

#### 3.1 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.<sup>1</sup> Augmented reality (AR), a variation of VR, can provide computer-generated environment overlaid with physical environments, allowing users to experience both worlds simultaneously.<sup>2</sup>

The technological progression has changed our everyday lives, but it has also shows the promise of impacting classroom environments and teaching methods.<sup>2,3</sup> While museums and libraries have already utilized 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.<sup>3-7</sup> This is especially true in the fields of science, technology, engineering, and mathematics (STEM), such as health science,<sup>8,9</sup> astronomy,<sup>10</sup> and engineering.<sup>11,12</sup> 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,<sup>13,14</sup> informational platform,<sup>15-18</sup> and a visualization tool.<sup>19-23</sup> Additional reports of using AR to increase cooperative learning environment are also available.<sup>24,25</sup>

Incorporation of AR in science classrooms or laboratories 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.<sup>26</sup> An augmented titration tool is an example of this advantage, where students can experience the titration experiment prior to interacting with chemicals through the AR application.<sup>13</sup> Aid in visualization is another commonly found benefit, as presentation of three-dimensional (3-D) objects become possible with AR rendering technology. One of the popular uses of AR in chemistry is the development of applications showing molecular structures in the 3-D format, helping students not only to understand various aspects of chemistry<sup>19,20,22</sup> such as

stereochemistry,<sup>27,28</sup> but also to increase their spatial ability.<sup>28</sup> In other cases, AR with marker-based targets can be used to simply link information to objects, including scientific instruments.<sup>4</sup> 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.<sup>16</sup>

Another example of using AR to link information to beyond marker-based target is a recently developed application called Augmented Reality in Educational Laboratory (ARiEL), which performs as an interface to connect general chemistry students to information about scientific instruments used in chemistry teaching laboratories.<sup>15</sup> ARiEL was made available for students taking a second-term general chemistry laboratory course. Students were prompted to use the interface during two experiments allowing them to read about pH and conductivity meters. The information included in the ARiEL application involved an introduction to what the instruments measure and how they measure the variables. Additionally, operational instructions in a form of list and video, a brief introduction to calibration, and a short note on safety were available.

The initial ARiEL report sought to measure student perspective on the application using the original version of the Attitude toward the Subject of Chemistry Inventory (ASCIv1) by Bauer,<sup>29</sup> with a minor modification. This modified semantic differential instrument was used in the study to measure the change in students' attitudes toward chemistry instrumentation before and after using ARiEL. A factor analysis results showed that the full ASCI exhibited a different factor structure when measuring students' attitudes toward instrumentation compared to the unaltered version used in measuring attitudes toward chemistry as a subject.<sup>15</sup> This study also found that with the availability of the ARiEL application, students' intellectual accessibility

measured by ASCI increased significantly. In addition, level of anxiety expressed by students decreased, indicating positive shifts in both cognitive and affective aspects of attitude.<sup>15</sup>

The current study is both a replication and an extension of the initial ARiEL study, 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. The interaction was followed using Google Analytics, which allowed the researchers to identify the landing pages accessed through the app and the subsequent flow of the website usage by the users. This tracking process allows the identification of the most sought-after information by the students, as well as to gauge understand how much of the information was being accessed. Additionally, the 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 experiments students were exposed to. This new page was added in hopes of allowing students to explore type of information not directly related to the experiment at hand, perhaps indicating their level of interest in learning about instruments.

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 through a series of semantic differential scales. The importance of assessing affective domain comes from the idea that incorporation of new knowledge into old ("meaningful learning") requires engagement of three domains: cognitive, affective, and psychomotor ("doing").<sup>30,31</sup> Laboratory courses are inherently centered around psychomotor domain,<sup>32</sup> and while cognitive and affective domain-centered research studies toward chemistry have been prevalent,<sup>29,33-41</sup> fewer studies have examined laboratory learning in relation to affective domain.<sup>32,42-46</sup> Moreover, characterizing and understanding students' affective states

towards specific areas of laboratory learning, such as instrumentation, is scarce. Therefore, this study seeks to build upon the initial ARiEL study by providing a second set of attitude measurement toward chemistry instrumentation.

### 3.2 Methods

#### *Course-wide Implementation and Data Collection*

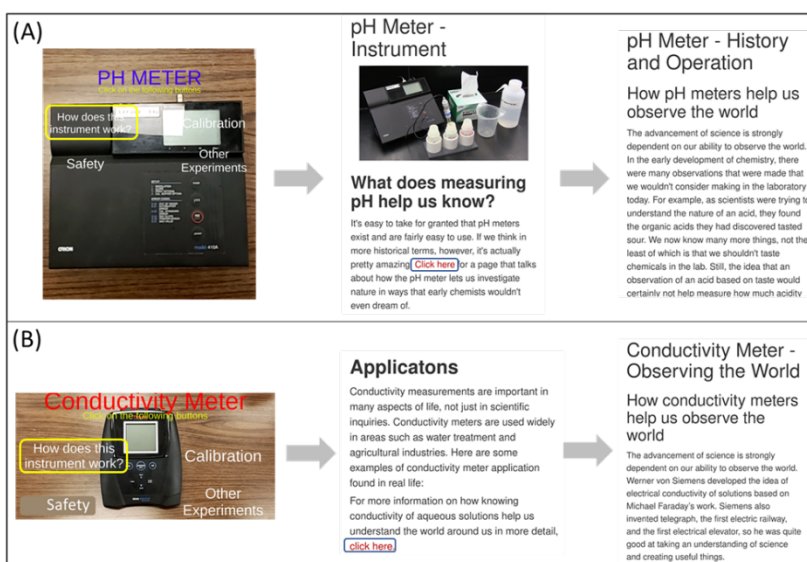
The following procedure was approved by the Institutional Review Board (IRB) as an exempt study (Appendix E). Participation in this study, from survey to application usage, was voluntary. The ARiEL application was made available in General Chemistry II laboratory course for a 2-week period, during the 6<sup>th</sup> and 7<sup>th</sup> weeks of the Spring 2020 semester, which occurred before any disruption caused by the COVID-19 pandemic changes. The target experiment spanning two weeks included the usage of both pH meter and conductivity meter.

As laboratory courses are divided into smaller sections and are supervised by teaching assistants (TAs), the researcher attended a staff meeting prior to the app implementation to inform the course TAs of the study's purpose and procedures. The TAs were asked to encourage students to use the application at least once during the target experiment during the two-week period. Based on the concern that not all students may own a compatible device or have access to the application,<sup>19,47</sup> they were given an option to choose to use ARiEL individually or as a group.

An announcement was posted on the Learning Management System (LMS) for the course with the pre- and post-survey instructions and links, as well as a detailed description of how to download the application for Apple and Android operating systems (OS). The pre-survey was available 4 days prior to the first day of the experiment, and the post-survey was available for 6 days past the last day of the experiment. The pre- and post-surveys were identical in a way that they included a consent form followed by the ASCIv1. As was true in the previous ARiEL

study,<sup>15</sup> the instruction for the ASCIv1<sup>29</sup> was slightly modified to refer to “Chemistry Instrumentation” rather than “Chemistry”. The post-survey also included System Usability Scale (SUS)<sup>48</sup> as well as two extra questions asking students to (1) indicate whether they used ARiEL during the target experiment, and (2) leave a short comment on what they thought of the ARiEL. No demographic information was collected during the study.

The ARiEL application in this study was linked to the same pages as the initial study,<sup>15</sup> but an additional page was added for both the pH meter and conductivity meter. This new webpage was embedded in the “Instrument” page of each instrument, and students were allowed to click on the link within the reading materials to access the information about history and importance of the instruments. The new information in the webpages accessed through ARiEL was not part of the course manual. Two other minor updates made were: adjusting the button sizes for different screen scales and changing the “Operations” button to a button that said “How does this instrument work?” to make it represent the information better. Figure 3.1 shows the changes made to the application as well as the flow from the application to webpages.



**Figure 3.1.** 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*

Once the two-week lab period was over and students had time to complete the post-survey, a data cleanup process was carried out, involving listwise deletion,<sup>49</sup> where any responses without consent, missing one or more responses, or the same pattern of responses were removed. The resulting total number of responses for the pre-survey was 280 student surveys. Similar deletion process was completed for the post-survey response, with an additional deletion criteria for those who indicated they did not use the application. The total number of post-survey responses for the ASCI and SUS were 132 and 104, respectively. Upon matching the responses using student ID, the number of students who completed both pre- and post-surveys was 111. A confirmatory factor analysis (CFA) was performed using pre-survey responses ( $n = 280$ ) as paired responses were not required to investigate the factor structure of the instrument. The  $t$ -tests were performed using both paired ( $n = 111$ , parametric) and unpaired (non-parametric) responses, but 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. This program was chosen for the fact that activities recorded are anonymous and the researchers cannot trace the website uses to each individual, as well as the ease of integration to the existing webpages. Patterns of usage were examined, such as which page students chose to visit first from ARiEL, number of drop-offs, the duration of website usage, and the user flow of the pages.

All statistical analyses were completed using R/RStudio. CFA was performed using the *lavaan* package (ver 0.6-5), and scale reliability measures (McDonald's Omega,  $\omega$ )<sup>50</sup> were calculated using the *userfriendlyscience* package (ver. 0.7.2).<sup>51</sup> The following fit indices were

utilized to determine the goodness of model fit: comparative fit index (CFI) > 0.95, root mean square error of approximation (RMSEA) < 0.06, and standardized root mean square residual (SRMR) < 0.10.<sup>52-55</sup> These fit indices were decided based on the widely accepted values discussed in literature. While Chi-square fit statistic is often reported with the above indices, it is no longer relied upon due to its extreme sensitivity to sample size.<sup>56-58</sup> Therefore, the Chi-square statistic is not reported in this study.

The SUS scores were calculated according to the scoring rubric,<sup>48</sup> where responses ranging from 1-5 were converted to scores over all items with a scale of 0-100. Scores closer to 100 refer to higher levels of system usability. The full scoring method can be referred to the original report of the SUS.<sup>48</sup>

### 3.3 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-off suggests that the novelty of the application may have provided initial motivation for many students to try it out. The most frequently chosen webpage, where approximately 33% of the total traffic started with, was the *Calibration* page for the pH meter. 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.

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 (16.4%), and the conductivity meter *Instrument* page followed behind closely at 14%. The remaining 6.6% consisted of a few occasions where students chose to visit pages such as *Experiments* or *Safety* first through the application.

The drop-off rate (the rate at which students discontinued the website usage) after the initial arrival to the webpage through ARiEL was approximately 83%. The 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, or (b) students were not interested in other information. The subsequent drop-off rates through the 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> interactions was nearly 70% on average, indicating that majority of students exited the webpage after each interaction. There was no expectation, in either of the lab experiments, that the students use information from the ARiEL site in their reports for the class. Thus, it may not be 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 practical motivations for students in the laboratory have been previously observed.<sup>46</sup>

Another important aspect to consider when looking at the interaction data between the participating students and the webpages through ARiEL was how much time students spent on the website. The time spent could be directly linked to the amount of reading students engaged in, which is ultimately the way to take in the information provided through the application.

Average session time was 2 minutes and 24 seconds. While this duration could refer to either

time spent on one page for some users or multiple pages for others, it is difficult to conclude that students would have had high intake of information during the average session.

Lastly, an additional page was included within the *Instrument* page for this study. This was an opportunity to assess how much students would be willing to read through extra information, even past the readily accessible information via ARiEL. Based on the Google Analytics data, the additional page with history, importance, and real-life applications was never accessed by students. This observation suggests at least two possible explanations. One, students did not read the content carefully enough to realize that there was an additional link embedded within the texts of the *Instrument* page. Two, students may have been willing to explore the webpages through ARiEL, but they were not required to digest all the information provided for them.

As the additional information provided through the app were not necessary in carrying out the target experiment, it can be suspected that students did not feel the need to engage in reading. It has been found in other studies that students are, in general, performance-driven, where they are most concerned with completing experiments early, and receiving good grades.<sup>46</sup> While the results of webpage usage were not particularly encouraging in terms of the amount of reading students engaged in through ARiEL, it is important to note that the ARiEL activity was not a part of the course requirements or assignments. Considering the previously reported student goals in laboratory courses and the Google Analytics observations made in this study, this type of resource may be more valuable for those students who desire more information about scientific process and instruments than what is normally available.

## ASCI

Confirmatory factor analysis (CFA) was carried out to test structures of the ASCI measuring students' attitudes toward chemistry instrumentation. Exploratory factor analysis (EFA) in the previously reported study<sup>15</sup> revealed a 4-factor, 16-item model, as shown in Table 3.1. The extracted factors were Intellectual Accessibility (4 items), Enjoyability (5 items), Satisfaction (3 items), and Anxiety (4 items). This scale structure (Model 1) was the first CFA model tested, which resulted in an inadequate fit (CFI = 0.853, RMSEA = 0.098, SRMR = 0.088).

**Table 3.1.** The full factor structure of ASCI measuring students' attitude towards chemistry instrumentation, based on the initial ARiEL study reported.<sup>15</sup>

Item <sup>a</sup>	Polar Adjectives	
<i>Intellectual Accessibility (IA)</i>		
1*	Easy	Hard
4	Complicated	Simple
5	Confusing	Clear
10	Challenging	Unchallenging
<i>Anxiety</i>		
14	Comfortable	Uncomfortable
18	Safe	Dangerous
19*	Tense	Relaxed
20*	Insecure	Secure
<i>Enjoyability</i>		
3*	Exciting	Boring
7*	Satisfying	Frustrating
8	Scary	Fun
12*	Interesting	Dull
13	Disgusting	Attractive
<i>Satisfaction</i>		
2	Worthless	Beneficial
11*	Pleasant	Unpleasant
15*	Worthwhile	Useless

<sup>a</sup> Scales were reversed for items denoted with \* for subscale score calculation.

Table 3.2 includes a list of all structural models along with their CFA results. While the 4-factor model (Model 1) did not result in adequate fit indices, this was not unexpected considering the difficulties ASCIv1 has faced in previous studies.<sup>29,33</sup> 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.<sup>29</sup> 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).<sup>33</sup>

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,<sup>15</sup> CFA was performed using a 2-factor, 8-item model consisted of Intellectual Accessibility and Anxiety subscales (Model 2). As can be seen in Table 3.2, improved CFI (0.944) and SRMR (0.057) values were observed, while a high RMSEA value (0.097) was still evident.

**Table 3.2.** List of CFA models and the corresponding fit indices.

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

<sup>a</sup> Thresholds utilized in this study: CFI > 0.95; RMSEA < 0.06; SRMR < 0.06.

In case of inadequate model fit, two paths are available.<sup>59</sup> One, return to EFA to examine the latent variables, and two, attempt to revise the scale by finding and removing problematic item(s) that are leading to inadequate fit.<sup>59,60</sup> Both methods were explored in this study, starting with the 8 items in Intellectual Accessibility and Anxiety subscales from the previous ARiEL study, in an effort to revise and validate the scale.

Data suitability for EFA was checked with Bartlett's test of sphericity and Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, and requirements were met. The results of EFA with maximum likelihood (ML) method and oblique rotation are shown in Table B1 (Appendix B). In general, a clear factor structure arose from EFA with 8 items, where items 1, 4, 5, and 10 loaded onto Factor 1 and items 14, 18, 19, and 20 loaded onto Factor 2. Item 14 (comfortable-uncomfortable) showed a relatively low loading value of 0.401 to Factor 2 while also showing a low loading value (-0.324) towards Factor 1. Negligible cross-loading ( $< 0.3$ ) was observed with items 1, 10, and 19. No abnormality was observed besides item 14, and the extracted 2-factor model was in line with the Model 2 (see Table 3.2) applied for the CFA analysis.

Modification indices (MIs) were examined as a second method to evaluate the scale. MIs are often evaluated for post-hoc model revision as large MI values point to possible areas responsible for model misfit.<sup>61-63</sup> The two items producing the highest MI values were items 4 (complicated-simple) and 14 (comfortable-uncomfortable). The cross-loading tendency of item 14 combined with large MI values obtained from item 4 indicated that the lack of model fit may have been caused by the two items. Based on these observations, 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 3.2 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.<sup>60,64</sup> Though removing one item from each subscale resulted in an acceptable model fit, the reason behind this 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 3.3 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 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 ( $\omega$ ). The commonly used and reported Cronbach's  $\alpha$  was not utilized in this study, as the CFA model followed the congeneric model rather than parallel, tau equivalent, or essentially tau equivalent models.<sup>50,51,65,66</sup> In this case, the use of Cronbach's  $\alpha$  can seriously underestimate the subscale



reliability. The  $\omega$  values for the instrument version of ASCI based on Model 5 are represented in Table 3.4. The subscale reliability level represented by  $\omega$  ranged from 0.74 to 0.77 for both pre- and post-surveys of the Intellectual Accessibility and Anxiety subscales. Reasonable  $\omega$  values indicate that the 3 items in each subscale collectively measure how students think and feel about chemistry instrumentation, specifically, the level of intellectual accessibility and anxiety toward instrumentation.

**Table 3.3.** Comparison of subscale scores<sup>a</sup> between models 2 and 5<sup>b</sup>, and comparison of pre- and post-survey scores within model 5.

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

<sup>a</sup> Scores represented in % (i.e., 1 = 0%, 7 = 100%).

<sup>b</sup> Refer to Tables 3.1 and 3.2 for the items in each model.

<sup>c</sup> No statistical significance was detected for the inter-group comparisons.

<sup>d</sup> Both significant after the Bonferroni correction for  $k = 2$  ( $\alpha = 0.025$ ).

**Table 3.4.** Scale reliability represented by McDonald's Omega ( $\omega$ ) for each subscale<sup>a</sup>.

Subscale	Pre-survey	Post-survey
<b>IA</b>	0.77	0.76
<b>Anxiety</b>	0.75	0.74

<sup>a</sup> Subscale of Model 5 (see Tables 3.1 and 3.2).

The pre-survey score of the Intellectual Accessibility subscale was 49.5% (see Table 3.3), 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. 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,<sup>33</sup> where the Intellectual Accessibility subscale was composed of the same items. It appears that the population of students, in the current and previous studies,<sup>15,33</sup> have a more favorable view of instrumentation than of chemistry as a subject. Nevertheless, the starting score of the Intellectual Accessibility subscale was only approximately 50%, which points at a possibility that this area of laboratory learning could be improved. As represented by the score change, providing an access to information regarding instruments during the laboratory period could be one way of making instrumentation more approachable for students.

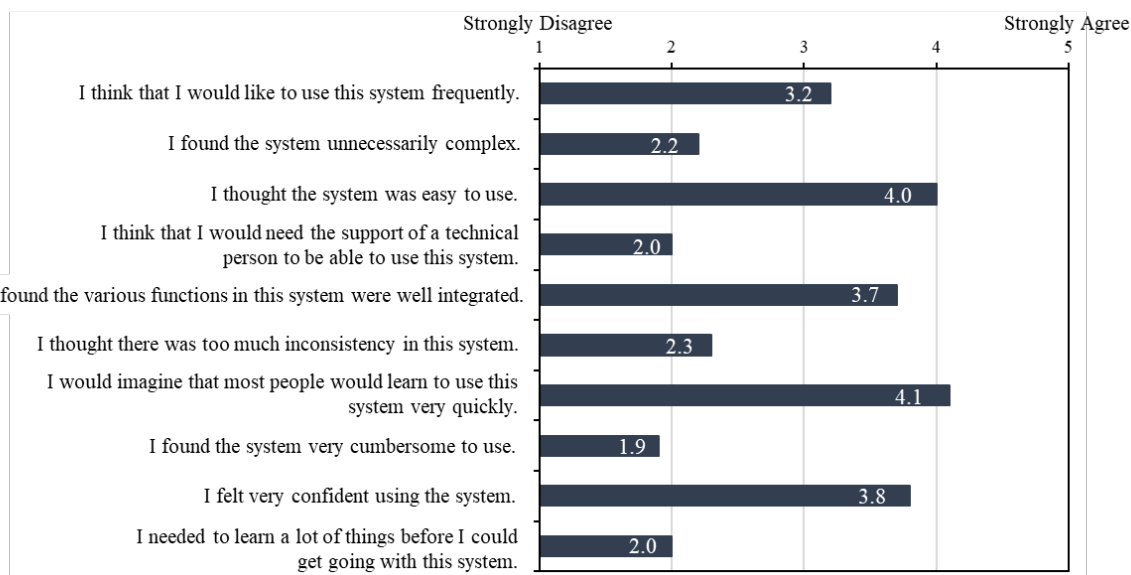
Similar results were true about the Anxiety subscale, where the pre-survey score of 42.9% decreased substantially by 5.3% after the target experiment with ARiEL. Judging by the pre-survey score of 42.9%, second-semester general chemistry students were not highly anxious about using instruments in the 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.<sup>42</sup> 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. For example, Table B2 in Appendix B 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,<sup>15</sup> 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 positive effects ARiEL had on students' level of anxiety toward instrumentation. The strongly similar results between the initial and replication study strengthen the argument that AR-based tool such as ARiEL could be a helpful resource for students in laboratories.

### *Usability*

The list of SUS items and corresponding median scores can be found in Figure 3.2. With 104 responses, the final SUS score for ARiEL was 71.0. The initial ARiEL study<sup>15</sup> reported a slightly lower SUS score of 69.5. While the difference is small, the minor updates made in the application after the initial study as mentioned in the *Methods* section may be responsible for the improvement. Acceptable SUS scores range from 65 to 70,<sup>67,68</sup> and the usability of ARiEL rated by general chemistry students for the second time was above the accepted level. In a study assessing various factors that influence system usability, the SUS scores were found to be affected greatly by the level of experience users previously had with similar systems.<sup>67</sup> Considering that no extensive instruction about the application was given to the participating students, and that the sample population consisted of students who had not been exposed to ARiEL before the study, the score of 71.0 may be interpreted as a lower bound of usability score for ARiEL.



**Figure 3.2.** SUS questionnaire and the corresponding average score (N=104).

### 3.4 Limitations and Implications

This study employed self-report type surveys, relying on responders to provide accurate description of their thoughts and feelings at the time of participation. As the entire study was based on voluntary participation, there also exists a possibility of selection bias.<sup>69</sup> The voluntary nature of the study resulted in participation rates ranging from 27% (post-survey) to 58% (pre-survey), based on the number of students enrolled in the course at the end of the Spring 2020 semester. The number of students who completed all parts of the study (pre-survey, app usage, and post-survey) was 23%, indicating that the results from the current study may not represent all students in the general chemistry II laboratory course. In addition, the participants could be those who are more inclined to use resources available to them compared to the larger student population.

Another limitation potentially revealed by the study is perhaps a lack of interactive functions of the ARiEL app. In the initial study, student comments pointed at their desire to see the app include more interactive features. However, this study focused on assessing how students

accessed reading materials through the app in order to better understand the effectiveness of AR interface in students' affective domain. While the Google Analytics results did not reveal deep engagement in reading, the modified ASCI data suggested the use and availability of ARiEL could still make a positive impact on how students view instrumentation.

The average duration of the session from Google Analytics, combined with the observation that students visited experiment-related pages the most, may be explained by the typical completion- and grade-oriented behaviors of students.<sup>46</sup> The intention of using ARiEL to provide real-time information about instruments' functions and the importance of observation can be challenging to promote to students who are accustomed to following numbered directions to complete an experiment each week.

Improving the level of interaction with a resource such as ARiEL could come from further updating the application. However, given that students often express feeling stressed due to time constraints they experience in laboratories,<sup>42,46</sup> laboratory environments where students feel free to explore various aspects of chemistry, including but not limited to working with chemicals and instruments, could be an important factor for promoting a deeper interest in all parts of the subject. As previous research studies suggest, laboratory instruction should be designed with psychomotor, cognitive, and affective domains in mind for meaningful learning to occur.<sup>32,70</sup> Laboratory courses are largely centered around the "doing" (psychomotor) with students following cookbook-style instructions, but how students feel towards laboratory activities can affect the quality of learning.<sup>71</sup> The improvement in how students feel towards instrumentation in this study imply that the availability of resources, like ARiEL, can be a valuable way to foster more positive affective learning in laboratory courses, particularly if the assessment structure of the course rewards such engagement.

### 3.5 Conclusion

The work presented here was both a replication and extension of the initial report of ARiEL, where the pattern of students' app usage was evaluated through the web traffic data. In addition, the ASCIv1 was further modified and validated using CFA. This modified version of the ASCI consisted of 2 factors and 6 items, and the new scale was utilized to analyze students' attitudes toward chemistry instrument for the second time. The modified ASCI results in the current work mirrored those of the initial study, confirming the positive effects ARiEL could have on 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 low. 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, but the most visited pages through ARiEL were experiment related. 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 benefits on students' attitudes. Nonetheless, further assessment of how laboratory courses can provide interesting and meaningful materials related to instrumentation is necessary.

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**CHAPTER 4****INVESTIGATING GENERAL CHEMISTRY STUDENTS' IDEAS OF THE ROLE OF SCIENTIFIC INSTRUMENTS**

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Modified from a manuscript to be submitted to *Journal of Chemical Education***Abstract**

Scientific instruments have long been a vital part of science, but the emphasis on the role of instruments is often not seen in science curricula. In this study, general chemistry students' views of instruments are investigated through a mixed-methods study based on how instrumentation connects to the concept of the nature of science. A survey was developed to assess students' ideas of how instruments are used outside of science and their interest in learning about instruments. Through exploratory factor analysis, two factors were retained with a good internal consistency. A semi-structured interview study was conducted to learn more nuanced views students held on the role of instruments in science, their connection to society, as well as students' practice of data evaluation and their motivation to learn about instruments. While a majority of students acknowledged some connection instruments had to science and society, only a few students displayed an advanced understanding of that relationships. Overall, neither students' views of instruments nor their interest in learning about instruments changed significantly after a semester of general chemistry. Relevancy and the usefulness of knowledge were often mentioned as sources of interest and motivation for students, showing that including the ideas of history and applications in relation to scientific instruments may be advantageous for enhancing students' understanding of the nature of science.

## 4.1 Introduction

One of the most common pictures people have of chemistry is perhaps an image of colorful solutions in different shapes of glassware, often with people wearing goggles carefully examining the solutions. While chemists' ideas of chemistry may differ from those of the general population, the fact that scientific instruments have been in the center of science, including chemistry, is frequently overlooked. This statement from one of the opening paragraphs to Holmes' and Levere's book, *Instruments and Experimentation in the History of Chemistry*,<sup>1</sup> provides an insight into chemistry and the history.

“This science [chemistry] has been, from its very beginnings, defined by instruments and apparatus comprising a repertoire of laboratory operations that its practitioners have employed to examine experimentally natural materials or the fabrications of human culture. [...] the history of chemistry has been overwhelmingly a history of chemical theory, with practice little considered and with the apparatus that rendered that practice possible almost entirely ignored” (pg. vii-viii).

If scholarship in the history of chemistry has tended to focus on chemical theories, it may be unsurprising that chemistry education tends to share this emphasis. The missed opportunity, however, is that students who learn theories without thinking of observations they explain only see a part of the power of chemistry and chemical thinking. A scientific instrument has been defined as “any specific contrivance or aid which may be used to carry out any particular physicochemical operation”.<sup>2</sup> As reflected by the quote, instruments encompass a wide range of tools. The development and the existence of various scientific instruments dating back to 1500s,<sup>1</sup> and especially in the past 100 years, have allowed science to advance rapidly.<sup>3</sup> Still, students in science classes typically learn relatively little about science history, and partly as a result are often unaware of the role of instruments in advancing science and scientific thinking.

### *Instruments in Education and Nature of Science*

Advocating experimental science in education began in the early nineteenth century.<sup>1,4,5</sup> Since then, laboratory activities have been not only a place where concepts were illustrated, but also where the nature of science could be understood by students.<sup>4,6</sup> Nature of Science (NOS), defined as epistemology of science,<sup>7,8</sup> has been a long-supported concept in science education.<sup>9-12</sup> A major motivation behind the support of incorporating NOS in science courses is to mold scientifically literate students.<sup>9,11-14</sup> Being scientifically literate involves understanding how scientific knowledge is generated,<sup>13,14</sup> which requires the understanding of several NOS ideas.

While different definitions and scopes of NOS exist in literature, there are some commonly agreed upon notions of NOS.<sup>7,8,15</sup> Among them are the empirical characteristic of science, the distinction between observations and inferences, and the idea that science is socially and culturally embedded.<sup>13</sup> The empirical nature of science refers to the fact that scientific observations are “filtered through the human perceptual apparatus”,<sup>8,16</sup> where direct observations of natural phenomena are often not obtainable. Related to the idea of observation is the difference between observations and inferences: observations are “descriptive statements about natural phenomena” (e.g., seeing an object fall to the ground), whereas inferences are “statements about phenomena that are not directly accessible to the senses” (e.g., the notion of gravity).<sup>8</sup> Lastly, science as socially and culturally embedded practice denotes how science is not only affected by society and culture, but it is also part of our everyday lives.

Although NOS encompasses several other concepts regarding scientific knowledge,<sup>7,8,15-17</sup> the empirical way of knowing, observations and inferences, and sociocultural science are three ideas especially relevant to scientific instruments that are discussed in this study. Ultimately, observations that can be made with human senses are limited, and much of scientific knowledge

is obtained with observations made with instruments, which allow us to create inferential theories.

### *Instruments in Chemistry*

Instruments are powerful tools used in modern chemistry, and students' experiences with them can have several benefits.<sup>18</sup> Some of the benefits of early exposure to instruments were provided by Steehler in his commentary to *Journal of Chemical Education*: "...including the motivating connection to real-life chemistry, the complementary nature of the type of laboratory experience, and the need to start learning these powerful [modern chemistry] methodologies".<sup>18</sup> Despite these benefits, many instruments are perceived by students as "black boxes",<sup>18-20</sup> meaning users are only concerned with instruments' functions rather than *how* they function.<sup>21</sup> A majority of general chemistry laboratory curriculum puts an emphasis on data that instruments provide rather than the process, which may promote students to think that results from instruments are the only important part of chemical experiments. While experimental procedures and data are important, it is also essential to help students understand how scientific information is acquired<sup>3</sup> (i.e., empirical NOS).

Perhaps a more widely emphasized benefit of laboratory course is the learning of experimental methods and concepts through the hands-on experience of handling chemicals and apparatus.<sup>22</sup> In addition to hands-on experience, laboratory courses involving instruments are an opportunity to connect chemistry to real-world applications. As evidenced by a recent rise in studies of systems thinking instructional approaches in chemistry education,<sup>23-27</sup> providing students with holistic view of chemistry is believed to be important. However, the idea that instruments enable humans to make scientific observations (empirical NOS), and that they have



wide applications outside of educational laboratories (social and cultural NOS), are often not highlighted in chemistry courses.

Despite multiple benefits of laboratory courses, the question of whether laboratory courses are worth the cost, both in terms of expense and labor, has been raised repeatedly.<sup>28</sup> Consequently, a great deal of reports in chemistry education research has been exploring how to improve laboratory education.<sup>28-38</sup> Among them, a limited number of studies focuses on instrument usage in chemistry laboratories.<sup>39-43</sup> Furthermore, studies that focus on both cognitive and affective aspects of laboratory learning centered around instrumentation are even more scarce.<sup>44,45</sup> Assessing cognitive and affective aspects of learning becomes especially important when considering the concept of meaningful learning. Laboratory courses are inherently oriented towards psychomotor learning domain,<sup>46</sup> but meaningful learning requires an engagement of affective, cognitive, and psychomotor domains.<sup>6,47,48</sup> If “doing” is inevitable, how students think (cognitive) and feel (affective) should be studied for effective laboratory education.

In a study where students’ conceptual understanding as well as their attitude towards instruments were assessed, it was found that students generally held positive attitudes about using instruments because of their connection to “real world”.<sup>44</sup> Based on their findings, the authors suggested that laboratory experiments should emphasize theory, purpose, and capabilities of instruments and techniques rather than repetitions of procedures.<sup>44</sup> Warner et al. investigated the impact instruments had on student learning in undergraduate laboratories.<sup>45</sup> They observed that the exposure to instruments through practical, hands-on activities affected how students perceived instrumentation.<sup>45</sup> For example, simply discussing instruments in lecture and laboratory without the hands-on exposure resulted in decline of knowledge about instrument

operation and data.<sup>45</sup> Improvement in problem solving abilities through instrumentation was also observed when students had more chances to work with instruments in similar contexts.<sup>45</sup>

### *Current Study*

The NOS concepts encompass the idea that many scientific knowledges, and our ability to make inferences, stem from the availability of instruments. Combined with the aforementioned studies, while they are limited in scope, the importance of instrumentation in chemistry learning is clear. Introducing students to the idea of NOS that science is empirical, where instruments are our way of making indirect observations of natural phenomena, may be important in increasing science literacy and instilling deeper understanding of how science operates. In addition, science is not separable from our society, and amplifying this view in chemistry education is deemed valuable as demonstrated by a handful of reports.<sup>36-38,49,50</sup>

However, it is largely unknown how students perceive the roles of instruments in science and society. In order for general chemistry courses to be able to incorporate the broader ideas of science based on observations in NOS, it is necessary to first assess the level of awareness students possess about instruments and their purposes. The current study aims to explore how general chemistry students conceptualize instruments using mixed-methods approach in an effort to identify another avenue for chemistry to be connected with real-world in higher education. A survey designed to gauge students' thoughts on how instruments are used in science and the world, as well as their interest in learning about instruments, was distributed to all general chemistry courses at a large public university. The survey was utilized to acquire a quantitative snapshot of students thinking on the role of instruments. An interview study was conducted to

gain a deeper insight into students' responses, to probe their understanding of NOS in relation to instruments, and to assess their affective states toward scientific instruments.

### **Research Questions:**

1. How do general chemistry students conceptualize the role of instruments?
2. Can a survey measuring students' ideas on the role of instruments be developed and validated?
3. Does systems thinking curricular approach influence the way students think and feel about instruments?
4. How interested are general chemistry students in instrumentation, and how do their level of interest change after a semester of chemistry course?

## **4.2 Methods**

The current study was carried out at a large public University in the Midwest region during Summer and Fall 2019 semesters. All procedures were approved by the Institutional Review Board (IRB) prior to the study (Appendix E).

### *Context*

The institution at which the study was carried out offers three different levels of general chemistry courses. College Chemistry course (1-semester) is taken by many non-STEM majors, General Chemistry for Engineering Students (1-semester) is taken by any engineering majors, and a two-semester sequence of General Chemistry (I & II) has many STEM major enrollments, including some engineering majors. A survey, described further below, was distributed to all three levels of general chemistry, including the General Chemistry II, at the beginning and end of the Fall 2019 semester. College Chemistry (CC) was taught by two different instructors, while Engineering Chemistry (EC) and General Chemistry I (GC-I) were both taught by three different instructors. One instructor taught General Chemistry II (GC-II) course.

Participation was strictly voluntary, and an announcement was made in each course by the researcher in the first or second week of the semester. An email announcement was sent out to all sections for the post-survey. The treatment group (1 of 3 GC-I sections) included both pre- and post-survey as two of several online assignments in which students can participate throughout the semester, gaining points for completing a certain number of the assignments. The survey was open for one week from the date of announcement, and it was made available on each course's Learning Management System (LMS) page for easy access.

The treatment group instructor regularly employed systems thinking ideas to connect chemistry concepts to contexts.<sup>26,27</sup> Tripartite learning outcomes<sup>23</sup> were utilized in the course such that students were encouraged to think of chemistry in terms of: Knowledge (what we know), Evidential (how we know it), and Relevance (why it matters). This format was designed to facilitate the introduction of students to the concept of systems thinking. The use of instruments in science was connected to many of the "Evidential" learning outcomes, which were then connected to the question of relevancy. The list of tripartite learning outcomes was developed by a group consisted of the course instructor and two chemistry education researchers. The tripartite learning outcomes were mentioned regularly (8-10 times) throughout the semester, but they were never explicitly included on lecture slides. The full list of learning objectives and tripartite learning outcomes that were included in the course syllabus can be found in Table C1 (Appendix C). In addition to the incorporation of the tripartite learning outcomes, students were given several online activities as optional assignments. These online assignments included (1) reading about chemists Antoine Lavoisier and Joseph Priestley, focusing on their inventions of instruments that contributed to discovery of gases (2) simulation of Beer's law, and (3)

simulation of photoelectric effect. All three assignments were related to the idea of instruments, and students were given a short quiz to complete after each activity.

### *Survey development and data collection*

A survey was developed based on four ideas related to the use of scientific instruments. These were: (1) how students think instruments are used in science, (2) how instruments are used outside of science, (3) their thoughts on data evaluation, and (4) their interest and motivation towards learning about instruments. Initial survey items were written by the authors to represent the four ideas, and the items were revised through several discussions. A version of the survey consisted of 18 Likert-scale items and 1 short-answer question was first implemented in a pilot basis in general chemistry I course in the Summer 2019 semester. The number of responses collected in the summer semester was low ( $N = 14$ ) due to low course enrollment. However, students' comments and suggestions were reviewed and utilized to further shape the survey questions.

The edited version of the survey included 16 Likert-scale items and 1 short-answer question. The list of questions is included in Appendix C (Table C2). The short answer question asked students to define "scientific instruments" in their own words. As noted earlier, the survey was administered through the course LMS, following announcements in each class surveyed.

### *Interview development and data collection*

To provide the opportunity to obtain more nuanced views students hold about instrumentation, semi-structures interviews were held with student volunteers from the course where survey research was conducted. Questions for the interview protocol were developed under the same four ideas as the survey. Initial scripted interview questions were written by the

researchers based on the survey items and refined through a series of discussion (Appendix C, Table C3). Potential interview participants were identified via the Fall 2019 survey, where students were asked to indicate whether they would be willing to be interviewed about the topic. The students who answered “yes” were contacted separately after the survey closed. Out of 68 students who were contacted, 14 students agreed to proceed. Each interview participant was provided with a consent form prior to the interview, and all interviews were carried out in a private room. The interviews were audio-recorded and lasted 36 minutes on average. All interview participants received a \$10 gift card as compensation for their time.

### *Data analysis*

#### Survey

All statistical analyses were performed with R/RStudio software. Before analysis began, listwise deletion<sup>51</sup> was performed where responses in one or more of the following criteria were removed: (1) responses without consent, (2) same responses for all items, and (3) missing one or more answers to Likert-scale survey items. All identifying information was deleted after the response deletion process. The remaining sample numbers for further analyses were 674 (pre-survey) and 386 (post-survey). Among these, there were 651 short answer responses for pre-survey and 382 for post-survey. The breakdown of sample numbers from each section of general chemistry courses can be found in Table 4.1. Even though two instructors taught CC and three taught EC, samples from these courses were combined due to low participation. Out of the three sections of GC-I, only one section incorporated a systems thinking curricular approach with an emphasis on instrumentation. This section is considered the treatment group and is listed separately from the other two combined GC-I sections.

**Table 4.1.** Sample numbers from each course for pre-survey and post-survey.

	CC	EC	GC-I	GC-I*	GC-II	Total
<b>Pre-survey</b>	144	99	188	172	71	674
<b>Free response<sup>a</sup></b>	137	95	183	169	67	651
<b>Post-survey</b>	53	29	129	134	41	386
<b>Free response<sup>a</sup></b>	51	29	129	134	39	382

<sup>a</sup> How would you define ‘scientific instruments’ in your own words?

\* Course with systems thinking instructional approach.

A free response question, “How would you define ‘scientific instruments’ in your own words?”, was included in the survey to capture the level of understanding students may possess about scientific instruments. All responses were analyzed by open coding.<sup>52,53</sup> An initial codebook was developed after examining the responses to gain ideas of the types of vocabularies present in the answers. Based on this observation, three categories of how instruments were viewed were identified: Classification (C), Uses (U), and Purpose (P). Within these classifications, in order to identify the level of understanding students held, codes designating three levels (basic, intermediate, and advanced) were added for each category. In the classification category, no student definitions were coded as advanced, so it has effectively two levels, despite the coding scheme allowing for three. The criteria for each level were decided based on the types of responses observed as well as the ideal level of recognition that at least some students in the sample displayed. The short-answer responses were coded by three researchers until 95% agreement was reached. A full codebook for the free response question is included in the Appendix C (Table C4).

Basic classification (code CB) included vague terminology such as ‘stuff’, ‘anything’, and ‘instrument’ without any elaboration. Intermediate classification (CI) included the word ‘instrument’ with elaboration of their purpose or uses, ‘technology’, ‘devices’, and ‘tools’. No advanced classification codes were assigned. With this classification level of definition, it is not

possible to solely be able to conclude the level of student understanding about instrument. Thus, two additional categories (Uses and Purpose) provide the remaining focus of this discussion.

The *Uses* category tracked student understanding of how instruments are used. Basic uses (UB) codes were assigned to responses that only mentioned ‘chemistry’, ‘laboratory’, or ‘experiments’. Intermediate uses (UI) codes incorporated wider range of recognition such as ‘science’ and ‘research’. The advanced uses (UA) code was given to the responses that specified that instruments can be used outside of science classrooms or laboratories (i.e., ‘life’ or ‘natural world’).

The category of the codebook requiring the most elaborate set of codes was *Purpose*, and this category represented how instruments are used based on the students’ definitions. For example, basic purpose (PB) included simple explanation such as ‘for scientific purposes’ and ‘conduct experiments’, as well as a vague reference to their roles (i.e., “figure things out”). Intermediate purpose (PI) was broken into two major pieces: data collection (PI-D) and assist in experiments (PI-A). The PI-D code was further separated into quantitative, qualitative, or both, as well as accurate or precise data collection. Lastly, the advanced purpose (PA) implied broader understanding of instruments’ purposes and functions. The PA code was divided to have five additional codes to better capture the types of advanced responses students provided.

As the survey used in this study was newly developed, a survey validation process was necessary. While the survey items were purposefully written to represent the four ideas related to instruments, exploratory factor analysis (EFA) was performed to examine the underlying structure of the survey items based on the data collected. Prior to EFA, a Kaiser-Myer-Olkin (KMO) test of sampling adequacy and Bartlett’s test of sphericity were employed to measure the data suitability for factor analysis.<sup>54-55</sup> The KMO measure of sampling adequacy (MSA) ranges



from 0 to 1, where values between 0.8 and 1 indicate adequate sampling for factor analysis (i.e., low partial correlations). Bartlett's test of sphericity is a test of null hypothesis that there is no relationship among items.<sup>56</sup>

Factor analysis uncovers underlying structure of a scale by using correlation matrices. Therefore, the type of scale utilized to measure observed variables must be taken into consideration.<sup>57</sup> Pearson correlation is generally used to achieve factor solutions, regardless of the data type. However, Pearson correlation assumes interval measurement scales, and it is not the optimal method for ordinal data (i.e., Likert-scale).<sup>57,58</sup> Employing Pearson correlation for ordinal data can result in incorrect factor loadings, leading to misinterpretation of the data.<sup>58</sup> Literature suggests the use of polychoric correlation when conducting factor analysis with ordinal data.<sup>57,59,60</sup> More detailed information on the type of correlation to be used in factor analysis can be found in the cited literature.<sup>57</sup>

One of the most frequently reported factoring methods is maximum likelihood (ML), which is based on normal distribution of data and residuals of correlation coefficients.<sup>61</sup> Ordinal data most always do not meet these assumptions, and the use of ML can lead to biased parameters.<sup>61</sup> Instead, Ordinary least square (OLS) method, also referred to as minimum residual ("minres"), should be used as it does not hold the normality assumptions of ML.<sup>62</sup> Considering these literature findings, EFA in this study utilized polychoric correlation with minimum residual factoring method.

As the purpose of EFA is to investigate the significant latent variables through factor structures, number of factors to be retained becomes particularly important in EFA.<sup>63</sup> Having an incorrect number of factors extracted can lead to detrimental errors influencing the results.<sup>63,64</sup> Some commonly used factor retention methods are Kaiser criterion and scree plot test. Factors

with eigenvalues greater than 1 are retained with Kaiser criterion, whereas scree plot test involves an examination of an eigenvalue plot for discontinuity.<sup>64</sup> While these methods are widely used, they involve subjectivity as well as uncertainty in decision making.<sup>64</sup> Parallel analysis by Horn<sup>65</sup> is a method that overcomes the weaknesses of the Kaiser criterion or scree plot. Parallel analysis, which determines the number of factors to be retained through a random data simulation, has been studied to be an accurate and robust method.<sup>66,67</sup> Therefore, this study determined the factor number based on the parallel analysis.

Internal consistency of a scale represents the degree of measurement consistency through items in a given construct.<sup>68,69</sup> Cronbach's  $\alpha$  is often used and reported to represent the scale reliability,<sup>70,71</sup> but there has been an increasing voice to caution careless usage of statistical measure of reliability.<sup>72</sup> Widely reported Cronbach's  $\alpha$  can be a biased measure of reliability under the violation of assumptions,<sup>73</sup> and psychometric measurements are frequently in violation of the underlying assumption of Cronbach's  $\alpha$ .<sup>72,73</sup>

As explained by Komperda, Pentecost and Barbera, an appropriate reliability measurement should be chosen depending on the factor model fitting the given data.<sup>72</sup> Typical psychometric measurements fall under the congeneric model rather than the parallel, tau equivalent or essentially tau equivalent factor models that Cronbach's  $\alpha$  can be used for. In congeneric model, each item has different degree of association to the common construct as well as different amount of error,<sup>72</sup> leading to underestimation of reliability with the use of Cronbach's  $\alpha$ . Considering the factor analysis results of this study, McDonald's omega ( $\omega$ , ordinal)<sup>69,70</sup> is reported as a measure of reliability instead of commonly used Cronbach's  $\alpha$ .

Subscale scores were calculated by subtracting 1 from responses of each subscale, averaging, and converting to percentage (0% = Strongly disagree and 100% = Strongly agree).

Item 5 was negatively worded, so responses were reversed before score calculation. One-way Analysis of Variance (ANOVA) was performed to compare the pre-survey subscale scores. An appropriate statistical analysis for the data from individual Likert-items would be non-parametric methods which do not hold certain assumptions such as normality. However, data resulting from Likert-scales approach interval data, meaning the use of parametric methods becomes appropriate.<sup>74-77</sup> Pre- and post-survey subscale scores were compared using independent *t*-test to assess any changes. The Bonferroni correction was utilized to adjust the  $\alpha$  values for multiple hypothesis testing.<sup>78</sup>

### Interview analysis

An inductive coding process was undertaken, where common themes were identified from the data.<sup>79</sup> After repeated review of transcripts, commonly arising themes were combined to create codes.<sup>80-83</sup> Initial draft of the codebook was continuously revised through discussions, coding of transcripts, and comparison of codes between two researchers. The credibility of the codes and the findings from the data were reviewed in weekly meetings with a larger group of researchers. This process was repeated until >95% consensus was reached between the two coders.

The full and final version of interview codebook can be found in Table C5 of Appendix C. Codes generated through the inductive coding process were divided into three domains of meaningful learning: cognitive (C), affective (A), and psychomotor (Pm). Thus, for example, when a participant in an interview made a statement related to a cognitive perspective of instruments in science, a code “C” was recorded. In addition to the codes belonging to these three domains, a few additional categories were created to represent other aspects of the interview questions and responses: a category for specific examples of instruments provided by

the interviewees (IEX), examples of instrument usage (EX), and purpose of instruments (P). Lastly, numerous sub-codes were written to be used along with the C, A, Pm, IEX, EX, and P codes. These sub-codes were often necessitated when participants were describing their reasoning related to an answer of a question prompt or follow-up question.

### 4.3 Results

#### *Survey: short answer*

Analysis of the short-answer responses of how general chemistry students define scientific instruments showed that majority of students thought of instruments as measurement tools used in science. Table 4.2 show a breakdown of codes by category for the GC courses collectively. Based on the pre-survey analysis, 70% of the *Uses* code assigned to responses was UB (see Table C4 for the codebook), meaning majority of students had basic ideas about instruments and recognized that they are used in laboratory or experiments exclusively. Only 7% of the codes in the *Uses* category belonged to UA, where students recognized the uses of instruments outside of science in their definitions.

**Table 4.2.** A breakdown of C, U, and P codes by category for all responses from GC courses.

Code Type		% within the Code Category	
Classification	Basic (CB)	30.0	
	Intermediate (CI)	70.0	
Uses	Basic (UB)	69.3	
	Intermediate (UI)	23.8	
	Advanced (UA)	6.9	
Purpose	Basic (PB)	PB	12.1
		PB-I	18.6
	Intermediate (PI)	PI-D	44.0
		PI-A	11.4
	Advanced (PA)	PA	13.9

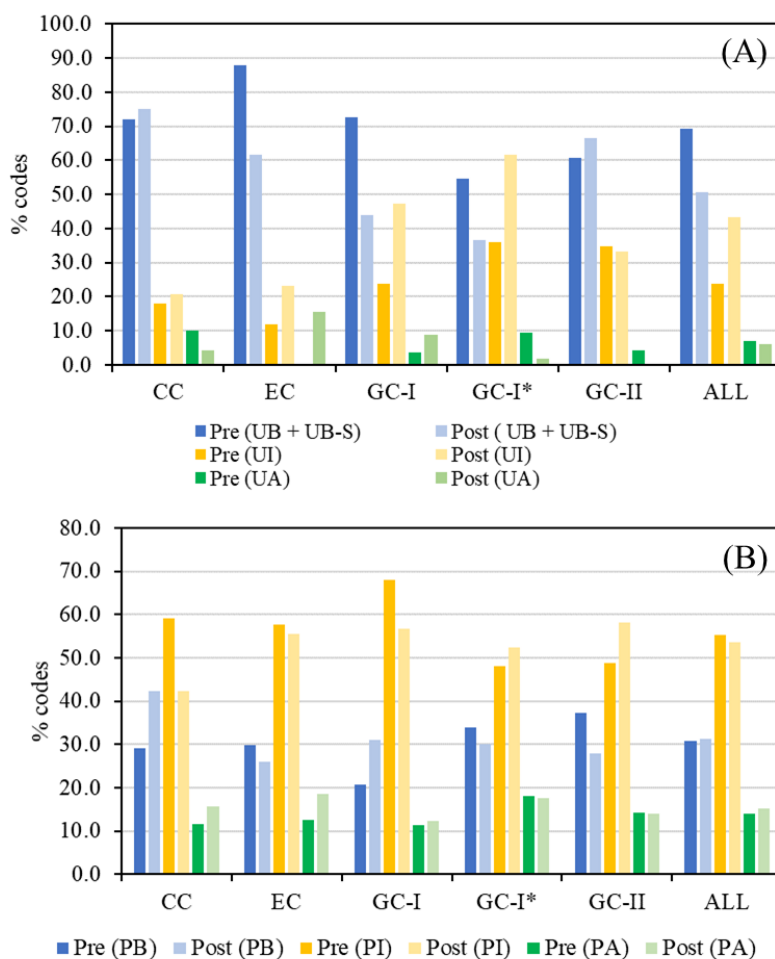
Approximately 31% of the *Purpose* codes were assigned PB, meaning students ideas of how instruments were used were vague. For the Intermediate level (PI), 44% of the codes incorporated the data collection function of instruments (code PI-D) in their definition. Other PI coded responses (11%) mentioned that instruments assist in experiments or research, but without any mention of how. Only 14% of the *Purpose* codes were in the advanced, PA, category, where students either identified instruments as tools used for scientific discoveries, explain natural phenomenon, or see and do things humans otherwise cannot.

The proportions of codes assigned to the post-survey responses remained similar to those of pre-survey. A decrease in the frequency of PI-D codes was observed, whereas the frequency of PI-A code increased by 5%. In other words, there were fewer students who specifically mentioned the data collection function of instruments, but there appeared to be an increased acknowledgement that instruments assist experiments or research in some capacity. These results suggest that the first-semester general chemistry student population as a whole did not show a significant change in how they defined scientific instruments.

Figure 4.1(A) shows a side-by-side comparison of % *Uses* codes assigned for student responses from different GC courses, both pre- and post-surveys. The frequency of UI codes increased after a semester of chemistry course for all GC-I students, as well as for EC students, but to a lesser degree. Another noteworthy observation is the emergence of UA code frequency for EC students in the post-survey. However, it is difficult to conclude that engineering students had a better understanding of instruments' uses at the end of the semester, as the number of participants in the post-survey was rather small ( $n = 27$ ).

Figure 4.1(B) shows a breakdown of *Purpose* category code assignments for each course between pre- and post-surveys. No notable change was observed in any GC courses, indicating

that students' definitions of the purpose of instruments were roughly unchanged after a semester of chemistry. The only course with some minor differences in the code assignments was CC, where there was an unfavorable shift towards the use of PB rather than PI codes between the start and the end of the semester. Once again, for the CC course, the sample number for the post-survey was much smaller than the pre-survey, making it difficult to determine if changes in the definitions supplied actually indicate that students had less developed ideas about instruments at the end of the semester. The GC-I course showed a similar shift, but to a lesser degree.



**Figure 4.1.** Side-by-side comparison of (A) % Uses and (B) % Purpose codes for each GC course based on pre- and post-survey results. See Table 4.1 for the pre- and post-survey sample numbers.

Overall, after taking a semester of some chemistry course, students' definitions of 'scientific instruments', had no observable changes. Considering that majority of students, with the exception of EC, are required to take the laboratory course concurrently, students appeared to view instruments the same way they did before receiving any university-level chemistry instructions. While the short-answer responses were analyzed to capture a snapshot of current general chemistry students' ideas of scientific instruments, the results showed that many students lacked the awareness of instruments' roles and their connection to society.

#### *Survey: Likert-items*

To consider the validation of the Likert-portion of the survey, all items showed a measure of sampling adequacy (MSA) above 0.6 (majority above 0.8), except for item 13 (MSA = 0.57). While MSA value of 0.5 is often discussed as acceptable threshold,<sup>84</sup> values ranging from 0.5-0.6 are considered "miserable" by Kaiser.<sup>55</sup> Some studies suggest retaining items with MSA values higher than 0.6 for a more meaningful EFA results.<sup>85</sup> As a result, item 13 was removed from the dataset prior to factor analysis. Bartlett's test of sphericity rejected the null hypothesis ( $p < 0.0001$ ), indicating that the data met the minimum requirement for EFA.<sup>86</sup>

Parallel analysis was performed to determine the number of factors to retain. Though the number of factors suggested by the parallel analysis appeared to be five, the unadjusted eigenvalue of 4 factors was nearly identical to the corresponding mean eigenvalue of the simulated data.<sup>87</sup> Therefore, both 4-factor and 5-factor structures were examined. It is important to note here that while methods such as parallel analysis can provide a valuable insight into the appropriate number of retainable factors, interpretability and comprehensibility of the data should be considered when making the decision.<sup>88</sup> Extracting five factors produced two factors

with three items each, one factor with one item, one factor with two items, and one factor with five low loading items. As two of the extracted factors cannot be retained due to low item numbers, 4-factor structure was further explored.

The 4-factor EFA structure of the pre-survey, using polychoric correlation and minimum residual factoring method, can be seen in Table 4.3. Generally, factor loadings below 0.3 or 0.4 are considered too low to be strongly associated with a factor.<sup>84,88-90</sup> Excluding the items that fall below the loading value of 0.3, the first factor included 4 items (3, 10, 11, and 15), the second factor included 4 items (1, 5, 9, and 14), and the third factor included 2 items (8 and 12). The fourth factor showed 6 items (4, 6, 7, 11, 14, and 16) with loading values above 0.3, but none of the items exhibited a particularly high association with the factor (i.e., factor loading  $>0.5^{90}$ ).

**Table 4.3.** EFA results of 4-factor extraction<sup>a,b</sup> using polychoric correlation and minimum residual (minres) methods.

	<b>Factor 1</b>	<b>Factor 2</b>	<b>Factor 3</b>	<b>Factor 4</b>
<i>Interest</i>				
Item 3	<b>0.666</b>			
Item 10	<b>0.466</b>			
Item 11	<b>0.619</b>			0.301
Item 15	<b>0.825</b>			
<i>World</i>				
Item 1		<b>0.676</b>		
Item 5		<b>0.559</b>		
Item 9		<b>0.655</b>		
Item 14		<b>0.302</b>		0.360
Item 8			0.703	
Item 12			0.746	
Item 2				
Item 4				0.432
Item 6				0.306
Item 7				0.410
Item 16				0.401

<sup>a</sup> Item 13 was removed due to low KMO MSA value.

<sup>b</sup> Factor loadings below 0.3 are not shown.



The items 3, 10, 11, and 15 had varying degrees of association to the construct, as evidenced by the factor loadings ranging from 0.466 to 0.825. Based on the list of items found in Table 4.3, these items as one construct can be best described as students' interest in instrumentation ("Interest"). The second factor including items 1, 5, 9, 14 were about roles of instruments outside of science labs, largely connecting them to everyday life ("World"). Item 14, with factor loading of 0.302, cross-loaded onto the fourth extracted factor at 0.360. After review of the items and factoring solution, it was concluded that the item 14 best belonged in the second factor for two reasons. First, the fourth factor possessed items with loadings between 0.301 and 0.432, which indicates that no single item was strongly associated with the construct. Second, the 6 items together did not appear to measure one recognizable idea, as the included items were about data, students' interest, and roles of instruments. As the goal of EFA was to identify underlying latent structure through the observed variables, retaining a factor that clearly included multiple ideas was deemed unacceptable. Lastly, while items 8 and 12 both had high loadings for one construct, a minimum of three items are needed to form a viable factor to measure a latent variable.<sup>89,91</sup>

Upon obtaining the factor structure, ordinal McDonald's  $\omega$  was calculated for each factor. The "Interest" factor containing items 3, 10, 11, and 15 showed ordinal  $\omega$  value of 0.78. The World factor with items 1, 5, 9, and 14 exhibited ordinal  $\omega$  value of 0.70. Both subscales exhibited reasonable internal consistency represented by  $\omega$ , and the items in each factor appear to have a similar underlying idea to each other. Subsequently, the subscale scores were calculated using the two factors.

Table 4.4 shows both subscale scores (%) for each course for pre- and post-surveys. The score from all pre-survey responses for the World factor was 70.6%, showing that students

generally thought scientific instruments contributed to their everyday life and that instruments had many uses outside of science laboratories (see Table C2 for items). The World subscale score ranged from 69.2% to 73.1% for all GC courses. Students in the engineering course presented a slightly higher factor score compared to students from other courses. However, one-way ANOVA results suggested that there were no significant differences among the courses in the World subscale score for the pre-survey. In comparing the World subscale scores between the pre- and post-surveys, it was noted that both treatment and control GC-I courses exhibited approximately 5% increase in the subscale scores. In other words, students became slightly more aware of the real-world uses of instruments. The independent *t*-test *p*-values for control and treatment GC-I sections were 0.00072 and 0.0016, respectively, which are below the adjusted limit of  $\alpha = 0.01$  ( $k = 5$ ) with the Bonferroni correction for multiple hypothesis testing.<sup>78</sup>

**Table 4.4.** Subscale scores for pre- and post-survey with independent *t*-test results.

	World		Independent <i>t</i> -test <i>p</i> -value <sup>a</sup>	Interest		Independent <i>t</i> -test <i>p</i> -value <sup>a</sup>
	Pre	Post		Pre	Post	
CC	70.4	72.2	0.4686	65.8	65.4	0.8929
EC	73.1	78.6	0.1071	69.4	73.7	0.1314
GC-I	69.2	74.9	0.0007244 <sup>b</sup>	67.2	66.0	0.4633
GC-I*	71.1	76.6	0.001599 <sup>b</sup>	67.6	67.0	0.7504
GC-II	70.3	75.3	0.07745	61.1	70.0	0.01113
All GC	70.6	75.4		66.7	67.3	

<sup>a</sup> *p*-value at 95% confidence level.

<sup>b</sup> Significant after the Bonferroni correction for  $k = 5$  ( $\alpha = 0.01$ ).

For the Interest subscale, scores ranged from 61.1% to 69.4%, with the Engineering Chemistry course once again exhibiting the highest score. General chemistry students appeared to agree, though not strongly, that they were interested in learning about instruments. Interestingly, students taking the second-term chemistry course (GC-II) displayed the lowest level of interest toward instruments. Based on one-way ANOVA, the pre-survey Interest

subscale score for GC-II was statistically different from EC (adjusted  $p = 0.0055$ ), GC-I (adjusted  $p = 0.037$ ), and GC-I\* (adjusted  $p = 0.024$ ), but not CC (adjusted  $p = 0.22$ ). The Interest subscale score from GC-II was potentially worrisome considering that these are students who have taken GC-I course in previous terms. The low Interest score of CC was somewhat expected, as students in CC course are not physical/biological science or engineering majors. The post-survey Interest scores ranged from 65.4% to 73.7%. The score remained unchanged for CC, and approximately 4% increase in score was observed for students from EC. It should be noted that both of these courses had far fewer participants in the post-survey than the pre-survey. The score for treatment GC-I group remained same, while the control GC-I course showed a small decrease in the score. The GC-II course showed the lowest interest score at the start of the semester, but a substantial increase was observed in the post-survey score. Even though some fluctuation in the Interest subscale scores were observed across the courses, none of the changes were statistically significant after the Bonferroni correction.

### *Interview*

#### Views on Instruments

Examples of scientific instruments provided by students tended to be the ones they are familiar with through science labs or recent experiments. For instance, commonly mentioned instruments were a thermometer, beaker/flask, graduated cylinder, calorimeter, pipette, and hotplate. In addition, students also talked about a burette, ruler, microscope, scale, and stopwatch or clock. Many of the items (e.g., beaker, pipette) are universally used not just in general chemistry laboratories, but in science laboratories as a whole. Instruments such as a calorimeter and microscope appeared to be mentioned by students who had recently completed experiments

involving them, whether in chemistry or in other science courses. A computer, dissection tools, calculator, x-ray, oven, and various types of sensors and gauges were mentioned as examples of instruments, but less often.

Students were asked to describe the utility of the example instruments they provided, and several aspects were noted. One of the reasons all interviewees stated was the instruments' function of measuring a variable (e.g., volume, mass, temperature). Glassware such as beakers were justified by their ability to aid in experiments. A few students ( $n = 4$ ) specifically mentioned that the function of instruments is allowing humans to observe or do what would otherwise be impossible. An example of this is represented by Student 2's response:

Student 2: "[...] usually the things that we studied are things that aren't really obvious. So like the smaller things, you'd have to use something to get...like, same with the microscopes, like you'd have to use something to be able to see what we can't see with the naked eye."

When the participants were asked to explore further, to consider the general purpose of instruments rather than only their utility, similar responses were noted. Majority of students placed an emphasis on instruments' measurement abilities, with some students recognizing their overall capability in helping humans carry out scientific processes.

Student 10: "I think it just helps us to find the answers of different questions that we would otherwise use longer procedures to."

Student 11: "Um, I would say, to like, help them do, like, the most accurate research, like, get the most accurate results, as they can, and like, be able to conduct any experiment that they want, to so that they can either figure something out, like prove, prove something or like, disprove something."

What these aspects (examples, utility, purpose) have in common is that they connect to the NOS notion of empirically based scientific knowledge introduced earlier, that instruments are used as a platform to observe what cannot be observed with human senses. Overall, only a small number of participants made this connection explicitly, with many students emphasizing instruments'

function as measurement tools. That a small percentage of students interviewed were able to connect the role of instruments to seeing otherwise unobservable phenomena suggests that some general chemistry students may hold a relatively informed view of instruments in science.

Moving beyond their classroom experience of instruments, participants were invited to think of an example where scientific instruments are used in life outside of laboratory (Q5, Table C3). Most interviewees gave examples such as measuring ingredients for baking or measuring dimensions with a ruler or a tape measure, primarily involving the idea of measurement in everyday life. Though simple, these examples provide preliminary evidence that students possess an ability to articulate the sociocultural-embedded aspects of science upon general prompting.

More technology connected measurement tools that were noted by some students were speedometer in automobiles and global positioning system (GPS). While many students thought of the aforementioned examples relatively easily, two students struggled to find any example at first, stating that instruments are not used outside of science. These two students, perhaps representing a small proportion of general chemistry population, were either unaware of how instruments are embedded in our lives, or have developed strongly compartmentalized knowledge about NOS and did not see how to extend that understanding into contexts that are not specifically science context confused.

Participant responses in the interviews quickly established the strong tendency to relate instruments to educational laboratory settings. This idea was unsurprising, and completely reasonable. Even within this large category, however, there are nuances about student understanding of instruments in the laboratory that merit further elaboration. For instance, the benefit of instruments in the laboratory setting was noted, such as when student 4 said:

Student 4: “As a student, like, taking chem lab and stuff, I think that they're all are really like beneficial and I use them a lot”

Some students acknowledged that there are probably more applications and usages outside of science and school that they are not aware of, or that their usages have become a second nature.

Students 3 and 14's responses illustrate these ideas:

Student 3: "I think they're probably a lot more relevant than I think they are. Like, they're probably in my life more than I think about them being there, if that makes sense."

Student 14: "I... I use... I guess, like, I use them every day. And I don't even realize it. And I think, like, that applies to a lot of things, even a simple thing like a clock. You use that all the time to measure, and... rulers all the time. Just kind of become a second nature. Like those little, like, everyday basic things that also apply to lab. Even thermometers. Yeah."

Other students expressed a combination of the two ideas, where they thought there are more uses of instruments related to her, but the connection was still primarily through school:

Student 7: "I think, in like, a raw, like, I'm sure there are a lot that I use in my life that I'm just, like, not thinking of as scientific instruments. But mostly what I think of is like through school."

Beyond recognizing basic uses of instruments in contexts outside of laboratory through cooking or other measurements, it was clear that the students struggled to deeply connect themselves to scientific instruments. Some students were aware there may be more uses, but they were unsure of what those uses might be outside of laboratory courses. However, three students seemed to understand the close relationships we have with instruments as well as the interconnected nature of instruments. The response from Student 6 depicts this idea:

Student 6: "I mean they're, they're...they're integral components of things that we use on daily basis [...]. I mean, like, generally we just, we don't live in naturally intended lifestyle. Like, we are in a building, with tools that you need scientific instruments to use, [...], to operate. So, yeah, it's fundamental piece that affect every part of our lives."

In a study assessing science instructors' ideas of NOS, a majority of participating instructors recognized the inseparable nature of science and human lives, portraying the idea that science is socially and culturally embedded.<sup>13</sup> Certainly, some interviewees here possessed a similar level of connection between science and society. Overall, however, the interview data

from this study suggest that a modest fraction of students appear to be aware of the sociocultural nature of science. This observation presents some concerns, given that literature emphasizes the need for science education to represent the sociocultural attribute of science.<sup>7,9,12</sup>

Beyond discussions about the aspects of instruments in both science and life, the depth of awareness students had about the connection of instruments in the two contexts was probed. The interviewees were asked to think of things still possible or impossible without instruments in the world (Q10 & 11, Table C3). Given this prompt, many students were concerned about the lack of quantitative data or accuracy of measurements, and Student 3's response shows this idea:

Student 3: "I feel like we wouldn't be able to put numbers to things. So, like, whenever we apply it, so measuring out miles when you drive or something like that, like, I feel like that factor would just be taken out."

Another common idea participants suggested about the absence of instruments was the possibility of difficulties in scientific processes, such as making discoveries of gases or atomic composition. Student 2 said:

Student 2: "Maybe like...atomic composition, so like, we can't really grab an atom and be able to understand what, what's going on. So, you're going to need all these different experiments to figure out like, oh, there's a nucleus, there's a negative charge positive charge, things like that. And we can't really do that on our own."

In this quote, Student 2 is synthesizing an understanding of the empirical nature of science by recognizing that some observations or inferences would be impossible to make without instruments. In total, three students recognized a wider impact that the absence of scientific instruments could bring, not just related to scientific experiments but also connected to the society. Take a look at student 13's response:

Student 13: "Wow, the implications of that question...Um... We wouldn't be nearly as far along. Specifically, the world of chemistry. [...] And without the discovery of the right instrument for the job, the process at which like that specific instrument was made for wouldn't ever had been finished. And outside of chemistry. I mean, if we look at our, look at cars, for example, like they

are, really, they are a piece of science, and the way they work and how we're moving forward with electric cars. And if we didn't, with electric cars, if we didn't have computers and different things, we wouldn't be able to model them and tune them and make them function properly. And so, I think, yeah, we'd be in a pretty sorry place.”

Clearly, student 13 and two other interviewees recognized that instruments were not confined to the world of science, and that their influences reach the aspects of life that we all experience on daily basis. Their view of instruments and science, represented by Student 13’s response, is in line with both empirically based and sociocultural-embedded NOS.

Nonetheless, in spite of these examples, the idea that using measurement, focusing exclusively on the quantitative measurement and data output functionality of instruments, was routinely presented by the students. This observation further elaborates the tendency of students to identify the focal point of chemistry laboratory courses.

As interviews appeared to suggest that students seemed to understand the impact instruments had on scientific discoveries, it was useful to consider the students’ perceptions of the way science moves forward. Thus, students were asked whether they thought instruments have contributed to scientific advancement. All interview participants agreed that instruments indeed have made contributions (Q13, Table C3), though their reasonings and the degree of acknowledgement varied. For example, Student 4 said:

Student 4: “I would definitely say so. Because of, like, what we were saying earlier about, like, being able to be sure of something, like, the mass or volume, even. If you were never, like, sure about that, then you can never be sure how many moles it is. And then you could never, like, have actually accurate calculations.”

The student 4, through their response, indicated that scientific instruments have contributed to the advancement of science by providing accurate, quantitative measurements, and ultimately enabling accurate calculations. Thus, this response again signifies the common theme that students view instruments as a way to enhance data accuracy and measurement.



On the other hand, three students, including Students 6 and 10, acknowledged the role of instruments in scientific progression at a different level:

Student 6: “[...] They can't contribute to the advancement of science because they, they play a critical role in the existence of science itself. Science wouldn't exist if instruments couldn't exist. I mean, it's the other way. You can have the instruments, and you can't have, and you might not have science. But you can't have science and not have instruments.”

Student 10: “Definitely. I mean, people have discovered or in during the earlier days, people just used to take such a long period of time to discover something. Like, when we study about atoms or something subatomic particles, we know that probably Rutherford's experiment was really long and complicated. And he might have taken years to get that done. [...] So it has the, I mean, it was like a bridge, like all these instruments are like a bridge that, you know, they just provide, like a shortcut or something. They're like catalyst.”

Thus, while perhaps a small fraction of students, there are students in general chemistry who can articulate a substantial understanding of the role of instruments in the progression of science.

Student 6 believed science could not exist without instruments, which was a view expressed by no other interviewee throughout the interview processes. This response provides a reason for optimism that more students can be reached to have deeper understanding of the central role instruments have had in scientific advancement, and why we should try to advance student understanding of NOS and instruments. Rather than stressing the data output or the “numbers” aspect of instrumentation in chemistry courses, guiding students to grasp the wider view of instruments, more specifically, how scientific observations and inferences are made possible through instruments, could be a valuable pedagogical approach.

An important motivation for this study was to ascertain what students perceive about the role of scientific instruments to determine how to teach the key aspect that instruments allow us to observe natural phenomena. Recognizing that science is a socially embedded practice, and that chemical reactions occur all around us whether we are aware of them or not, can students be guided to better understand how observations advance both science and scientific thinking?

Cooking and baking are some of the commonly encountered platforms where chemical reactions occur, and many students recognized this during interviews. To push further, and to understand how mindful students were of the chemical observations outside of science, participants were shown a short video of a souffle rising as it bakes in the oven. Following the video, students were asked whether there is any difference in how they make observations between real life situations (i.e., in the video) and lab settings.

All students, to some degree, agreed that observations are different in these two situations. The most common difference was the degree of observational details they may pay attention to. Students answered that they purposefully make detailed notes and observations in lab for experimental purposes, whereas any observations they make in life would not be nearly as detailed. It was also emphasized that more detailed quantitative observations would be common in lab, whereas qualitative observations are enough for real-life situations. This was yet another example showing that students are focused on the quantitative aspect of chemistry.

Along with the level of detail, most participants also mentioned that they often do not think about chemistry outside of the laboratory context, separating life experiences from the laboratory or scientific experiences. An example response for this reasoning can be seen in student 9's quote:

Student 9: "I'd say it is probably different, because you're not thinking about it, like baking, most people don't think about how it's going to produce a cake, or chemically what's going to happen. Um...you kind of just go on through the day, you just like mix your cake, you bake it, and cool, you have a cake and you are going to eat it. Um, in chemistry you are specifically thinking about how things are going to react and why they're going to react. How does like, how do the reactants turn into the products, what's required to make it happen."

Among the participants, only three students did not suggest there were significant differences between the two contexts, and these students all indicated that they often think about chemistry behind phenomena they come across in life, such as baking, without being prompted

to do so. The responses here show a glimpse of the reality that for majority of students, there exists a separation between science and life rather than thinking of science as socially embedded practice.

### Data Evaluation

While students may be susceptible to overlooking the role of instruments in the way science progresses, they are likely to recognize the role of data. This concept was demonstrated by the results noted earlier that measurement and accuracy were common concepts of instruments mentioned by the students. As one of many psychomotor (“doing”) learning<sup>47</sup> focused on in typical general chemistry laboratory courses is collecting data, one of the ideas the authors wished to explore through the project was how students treat the data that they obtain from instruments. The interview participants were asked whether they evaluate their data in lab, and if so, how, as well as why or why not they think it is important to evaluate the data. Roughly 2/3 of the students said they evaluate their data, whereas the other 1/3 indicated they only do so occasionally. Comments from students tended to show an instructor effect, based on the role of the TA in the laboratory. Of the 9 students who indicated they engage in data evaluation, 2 students specifically said they do so as a class with their TAs. Student 14 talked about forming a habit of engaging in data evaluation over time, owing to the TA’s effort of leading a discussion after each experiment:

Student 14: “My TA [...] leads a postlab discussion every time, where we talk about what happened, and if everyone got that result, and why it happened. And then, if you didn’t get that result, why that didn’t happen. So, errors and things like that. So, I guess her doing that kind of got me in the habit of thinking that way.”

Student 14 specifically indicated that evaluating data was not part of her scientific practice before this course. Thus, student 14 serves as an example of students in chemistry courses may

require explicit instructions or demonstration of why such data were collected and what can be inferred from them, rather than the emphasis on the action of collecting data.

Five students mentioned that the level of understanding of the experimental concepts was important for being able to evaluate their data, and it was also a reason behind practicing data evaluation only occasionally. A second reason for occasional data evaluation was time constraints. For all students, the most common strategy used for data evaluation was comparing to their expectations of what the data should look like, followed by comparison to other students' results in the class:

Student 4: “Uh, I guess I kind of depends on how much time I have. I kind of think in my head if it makes sense a little bit, like, before we move on.”

Student 8: “I do a little bit. When I’m comparing my data with that from other groups. Just to see. Okay. Did something go drastically wrong that I didn’t realize? So I would say yeah, not so much for seeing if it’s logical in that sense, but more that it’s accurate based on what was going on in the classroom.”

The common strategy of comparing data to expectation suggest that students need to have a solid understanding of the experimental concept before the experiment, hinting at the importance of pre-laboratory preparation. In addition, time constraint appears to be an element that affects students' behaviors (i.e., frequency of data evaluation) in laboratory courses. These ideas echo the findings of previous reports studying the importance of pre-laboratory preparation and the effects of numerous pre-laboratory activities have been studied.<sup>92-96</sup> Furthermore, feeling a constraint for time in laboratory has been reported in other studies as an affective factor that influences students' behaviors.<sup>46,97,98</sup>

While instructor effects were present for interview results about data evaluation, all participants answered that data evaluation is an important practice. The main reason noted was because there are many opportunities for errors to occur throughout their experiments. Many

students were concerned with the correctness of the data and the effect it may have on the assessment. The following responses from Students 9 and 11 represent this idea:

Student 9: “You don't want to mess it all up. So you can, there are always mistakes, although a lot of times it's human mistakes, you are not allowed to write that [in the report].”

Student 11: “Mm... I think just probably fear of having the answer wrong. Like, I don't want to present the wrong data. [...] When you go back and like, write your lab reports, it's going to be a lot harder if you have data that doesn't make sense.”

However, several students expressed that catching potential errors is not just to receive good grades, but it is to understand the experiments. Students 7, 10, and 14 all had the same idea:

Student 7: “Because, like, I know I'm not just like in a class for the grade, and I'm in the class to learn the material for the future. So, performing an experiment isn't really learning. [...] It's giving you the opportunity to look at what you did and learn from that.”

Student 10: “I think it is very important, because I mean, it's not something that's essential, but then again, you do want to know what you're trying to do because otherwise there's no point. [...] Plus, it helps you strengthen your core concepts and everything. [...]”

Student 14: “Well if you don't, it's kinda like what was the point of doing it, I guess. You wanna know why that happened, I guess.”

These observations are not completely universal, however, as exemplified by student 8 who had a mixed opinion, where the importance of data evaluation was dependent on the context. His reasoning of importance as a student was more because of the performance and completing given tasks, rather than understanding of experimental concepts.

Student 8: “I would say, in academic setting, where I am just filling a requirement, I don't find it nearly as important as if I were out doing research on my own. Looking towards collecting data for like, like a research purpose where I would be publishing something. Um, so I don't find it nearly as important as that. [The difference comes from] I think it's a little bit motivation, someone who is researching is motivated to get the correct answer so that they can share what they found and be credible with that. Whereas the student perspective is more of just that getting the good grade and making sure everything's complete.”

It is important to note that while all interviewees recognized data evaluation as an important practice, not all students participated in it for every experiment. As mentioned previously, 1/3 of the interviewees indicated engaging in data evaluation only sometimes, and a few with the explicit guidance of their TAs. How students thought of data and their practice in laboratory were partly mismatched. Some students emphasized the correctness of data for the purpose of Student opinions and practices regarding data evaluation raise several potential shortcomings of current general chemistry laboratory courses: emphasis on the correctness of data, leading to underemphasizing the process of making observations with instruments, and the inference making processes that ultimately form scientific knowledge, as well as the differing effects TAs or instructors can have on students' scientific practices.

#### Views on Learning about Instruments

When it comes to learning, how students feel is deeply connected to how they think and behave.<sup>46,48,99,100</sup> The initial part of this study focused on cognitive (i.e., students' views on instruments) and psychomotor (i.e., how students evaluate data) domains of instrument learning in chemistry laboratory, but it is important to keep in mind that meaningful learning requires an engagement of three domains: cognitive, psychomotor, and affective.<sup>48</sup> To investigate students' affective states towards instrumentation, questions about feelings and motivation were asked. Mixed feelings were expressed by students about how they feel towards instrument learning, and these mixed feelings can be seen in student 2 and 7's responses:

Student 2: "I mean, I like using them, when I know how, but like, learning how to use them is like pretty boring."

Student 7: "Um, kind of mixed. [...] It's kind of difficult to figure out exactly how they work. But once I get it, it makes the experiments a lot easier. [...] I'd say, I'm mostly, I'm curious

because I know how helpful they can be. And also, a little apprehensive that I'm gonna mess it up or break something.”

While a few students voiced negative emotions, approximately 2/3 of the interviewees held positive feelings about instrument learning for various reasons, including the usefulness of knowledge for future and simply wanting to acquire more knowledge. The following quotes from students 1 and 8 show both sides of the reasoning:

Student 1: “Oh, yeah, yeah, I think those are really cool. [...] I think it'd be useful, you know, anytime down the road, we may have to do titration for some reason or something like that.”

Student 8: “Um, I think that there's always something new to learn about, and I think it is helpful to expand your knowledge of different instruments, whether you, your focus is in science or not. I think it's just useful for the development of society and you as a person.”

Negative affective states have been observed with students working in laboratories<sup>46,97</sup> for reasons including fear of using equipment.<sup>98</sup> For the participants in this study, feelings toward instrument learning were mostly positive, but it was of interest to analyze how students react to a situation where they are starting to learn about a new instrument. In this situation, 8 out of 14 students expressed negative feelings such as being anxious and scared. Reasons ranged from feeling pressed for time to being afraid of breaking the instrument.

Student 5: “I get a little anxious that I'm going to do something wrong with it. So I definitely have found myself reading the lab information over and over, because I want to make sure that I don't miss any little detail. So definitely, like, over preparing myself before I use it, because I don't want to break it or something like that or use it incorrectly.”

Student 5's response, again, shines a light on the impact that the level of preparation could have on how students feel about in-lab activities. This may be especially true when students perceive they have a limited amount of time to complete experiments. The response from student 7 illustrates the student perception of the time-constricted nature of lab learning:

Student 7: “Uh, nervous. Yeah, especially because, like in a lot of labs, things are kind of time sensitive, so you don't really have a lot of time to kind of work and figure out how things work.”

The perception of time intensity in the laboratory and the importance of preparation noted here were also mentioned by some participants regarding data evaluation. Providing an ample amount of information on not just procedures, but also on instrumentation, may be a helpful method of reducing the in-lab pressure, whether it is for time or misuse of instruments.

Given that both positive and negative feelings were present for laboratory learning, a question arises as to what motivates students to overcome the negative feelings in instrument learning. For most students, the source of motivation to learn about instruments in lab was related to their performance in the course. Performance-driven desire to learn in lab has been demonstrated in other studies,<sup>97</sup> thus it is unsurprising that students' motivation to learn about instruments was based on the same goal. The next most commonly mentioned factor was the potential usefulness of the knowledge in future careers. The least popular source of motivation was an inherent desire to know, in other words, intrinsic motivation. Three students indicated that the motivation to learn comes from wanting to know and understand the process. For example, student 6 said:

Student 6: “[...] what motivates me personally, [...] chemistry is everything. You know, it’s the manipulation of the world around us, it’s one of its most fundamental levels. Like, that's motive, that should be motivation enough to just do it, and learn about it. It just makes sense to me.”

As observed in chemistry lecture courses,<sup>101-103</sup> intrinsic motivation was not a common purpose behind learning about instruments. External sources of motivation, such as course grades or potential use of the knowledge in the future, were overwhelmingly common within the interviewees.

Whether students expressed positive, negative, or mixed feelings about instrument learning and regardless of their source of motivation, all but one interviewee acknowledged the importance of learning to various degrees ranging from slightly to very important. For many



students, the importance arose from the expectations of future usefulness of the knowledge and course performance reasons. Major area of study was also related to how important they thought instrument learning was to them. Student 4, who was a chemical engineering major, said:

Student 4: “To me, I think is pretty important just because I'm going to be using a lot of those things in the future. And they'll be beneficial to me. But to someone who's like a business major, it wouldn't be as important.”

There were, however, examples of students with more expansive views about the value of knowledge about instruments, such as this quote from Student 13 on the interconnected nature of science and society:

Student 13: “I think it's really important. Because if we didn't take the time to learn how things are done and learned about how society is conducted, like, you personally would never grow, because you can, it's like, because I mean, there's scientists and there always will be and people that are professionals that like, whether they're chem professors or people that get a degree in Chemistry or Chemical Engineering that will continue to always for the advancement of chemistry or whatever craft it is. You can always rely on those people. But at the same time, I think as a people, we can't just expect others to do everything for us. And so I think it's really important for us to take the time to grow, and to learn about how things are done.”

Students holding positive views on instrumentation due to the potential usefulness of the knowledge and the connection to the real world was seen in a previous study.<sup>44</sup> A possibility that their experience with instruments could become useful in the future was widely recognized by majority of the interviewees in this study, but the potential of connecting chemistry to the real worlds was seldom mentioned. Thinking within the NOS framework, the lack of realization regarding socially and culturally embedded nature of science was present here.

Many of the instruments students encounter in laboratories are technological in nature, much like computers and phones we are familiar with in the modern era. Because the current generation of students are exposed to many types and levels of technologies inside and outside of labs, the interview also included prompts designed to elicit an understanding of how students

view new technologies compared to new instruments (Q16, Table C3). Twelve students indicated they feel differently about technologies compared to instruments. The difference came from the relevancy to their lives, giving them more incentive to struggle through learning how to use the technologies. Here is what student 11 said in response to the question:

Student 11: “Yeah, I think just because of, like, how we've grown up is so, like, technology and social media based, that something like that isn't scary to us, because that's...we want to do that, as bad as that sounds. Like, a lot of people when they are in chem lab, they don't care to do it, they are just doing it to get past the lab. Whereas that's more personal life, and personal life interests people a lot more.”

Interestingly, two students stated that the difference was partly because the timed laboratory experiments make them nervous to learn about instruments in lab, as seen in the earlier quote from Student 7. By contrast, another participant indicated that the determining factor on how she felt about technology or instruments was the inherent interest she possessed towards each item. Students finding technological devices (e.g., phones) more interesting because they are more relatable is yet another indication that the role of instruments in society should be highlighted in chemistry courses. Doing so may not only enlighten students about NOS, but it may also increase their interest in chemistry instrumentation.

As many students revealed their desire to learn instruments in laboratory comes from course-related reasons, understanding the elements of motivation outside of courses was thought to be helpful in designing future instructional approaches. Beyond lab, desire to learn about instruments was low. Eleven interviewees said they are not motivated to learn about instruments past what is required of them in each laboratory section. Yet again, relevancy to their lives was a contributing factor to how much they feel motivated to learn. Out of the 11 students who did not show much motivation to learn instrumentation beyond the laboratory period, 7 students indicated their motivation would be higher if the instruments were more applicable to their lives.

This provides another validation to incorporate sociocultural contexts of science into chemistry courses. A quote from Student 4 represents the recurrent idea of relevancy:

Student 4: “Um, I guess... Honestly, I’m not like super motivated because if I, if I don’t have to use them, like, I just feel like that’s space wasted in brain. Yeah, like, if I’ll need to do something at some point with like that something then, I’ll be more apt to like learn about it and learn how to use it.”

In order to assess students’ own judgment on how their understanding of instruments may have changed as a result of experiencing the interview, they were specifically asked to comment on “Has your definition of scientific instruments changed at all?” (Q26, Table C3). Four students (36%) responded that their idea of instruments changed, stating that they realized there are more applications and uses of instruments than they had initially thought:

Student 5: “Yeah, I think it has. I think that I realized that there are so many instruments in, that I encounter every day and that...that they are like a big impact on our lives even if we don’t really realize it.”

Nonetheless, most interviewees thought their understanding of instruments had not changed due to experiencing the interview the interview. Somewhat oddly, however, two of these students changed definitions of instruments and their functions during the interview, apparently without realizing it. Those changes led to expanding their views of scientific instruments. Some of the other students also showed increased understanding of instruments and their uses as the interviews progressed. For example, students 7 and 12, who could not provide an example of instrument usage outside of lab at first, were able to think of multiple examples towards the middle of the interviews. This observation may point to a possibility that students need explicit assistance to understand the role of instruments and the ideas of NOS, whether through thought-provoking questions or incorporation of real-life examples.

Another finding worth noting is that four out of nine interviewees from the treatment section mentioned the online assignments which were a part of the systems thinking instruction.

They often mentioned it to explain that without instruments invented by scientists, understanding gases would have been impossible and the subsequent scientific discoveries would have not been made. Students from the treatment group also presented positive reactions to the assignments as well as the systems thinking instructions, indicating that they enjoy being able to make the connections between concepts and history as well as applications.

To conclude the interview, students were asked if they thought the learning about instruments in their current laboratory course was sufficient. Approximately 3/4 of the interviewees thought what they were learning was enough, with one student specifying that she the reason why she feels positively about the current laboratory learning was because of her TA. The remaining 1/4 of the interviews were not satisfied with the level of learning, with one student identifying the lack of explanation by the TA as the reason. The other two students expressed that they wish there were more applications and bigger picture ideas incorporated into instrumentation and experiments.

When asked what could be done in lab or lecture to improve learning about instruments, common suggestions were to include more demonstrations, background information on instruments, and emphasizing the importance of using them. Many students also wished to have more connections to life examples, stating that learning about applications help them stay interested in the topic. A few, however, indicated that lecture and lab are separate, and this idea can be seen in Student 9's response:

Student 9: “[...] lecture and lab are separate, I wouldn't feel that the lecture needs to discuss all the instruments. It's more about the theory and the math while the lab is the hands-on stuff where you're actually using it. So like, instrumentation should be kept more towards the lab area.”

While this was an unusual impression given by two students, it still presents a challenge general chemistry courses may face relating lectures to laboratory activities. If laboratory learning is a

part of a chemist's identity,<sup>104</sup> and therefore a large part of a chemistry curriculum, separation of laboratory from other chemistry learning environments should not be supported.<sup>105</sup> Instead, laboratory and lecture courses should be considered mutually reinforcing in fulfilling the pedagogical goal of laboratory: teaching "how to do chemistry".<sup>105</sup>

#### 4.4 Discussion and Implications

Looking at the survey results, after removing one factor due to low number of items, and another factor for the reason that the items did not seem to hold together to measure one variable, the remaining scale included two factors with four items in each factor. The retained number of items after EFA was half of the number of items the survey initially contained. The difficulty experienced in creating a scale that measures students' understanding of instruments may be attributed to several reasons. As observed during the interviews, students possessed a wide range of understanding about the topic. A few students presented advanced awareness of the instruments' usage inside and outside the science as well as their interconnected nature, whereas a majority of students showed fragmented knowledge of how instruments were connected to life. If there is a wide range of experience and interest present in the sample, different participants will likely have different latent structures about the topic, and a factor analysis that would require overall similarities may be difficult to construct. Secondly, some instructor (TA) effect was present for student practices of data evaluation and the level of interest students showed toward instrumentation. Considering that general chemistry students may not have a concrete knowledge of scientific processes, laboratory TAs leading each lab section can greatly impact the way students think and feel about instruments based on near-peer teaching/learning.<sup>106</sup> Once again, inherent experiential variability in the sample could easily be reflected in the observation of

inconsistent latent variables and relatively poor factor models for the whole sample data.

Therefore, while the newly developed survey was modified using EFA to measure (1) students' views on the roles of instruments in the world and (2) their interest in learning about instruments, a modified survey designed with a 2-factor structure should be further validated in a future study in order to support the results obtained from this study.

Judging by the survey subscale scores, general chemistry students appeared to understand the broader uses of instruments outside of the laboratory settings to a certain extent. At the end of the semester, the World subscale scores had increased significantly for all GC-I sections. Interview results suggested that a small number of students had advanced views on the instruments' usage in and outside of science, while others exhibited more compartmentalized views.

The role of scientific instrument is expected to be most strongly connected to the "*How we know it*" column of the tripartite learning outcome. Students, however, may find connections to the "*Relevance: Why it matters*", a challenge, leaving an impression that instruments are important simply because they are capable of making measurements in the laboratory. Thus, having the tripartite learning outcomes available in the syllabus and referred to multiple times throughout the semester may not have been enough structure for students to find them highly meaningful. The related contexts ("*Why it matters*") may need to be emphasized more explicitly for a large group of students to see their importance, both in terms of content ("*What we know*") and in terms of observations of nature ("*How we know*").

Students' interest in instruments remained the same after the semester regardless of which general chemistry course they were enrolled in. Thus, the course that incorporated tripartite learning outcome structure did not appear to affect student integration of the nature of

science in terms of observation of nature to the intended context. This observation may be another indication that students require more reinforcement when contexts are presented along with the content. Based on these results, future study will focus on delivering instructions that directly integrate the tripartite learning outcomes, connecting each lecture to What, How, and Why ideas to encourage students to understand the interconnected nature of instruments, science, and society.

Based on the interview study, it was apparent that students' previous scientific experiences affected their current knowledge of instruments and how they are used. For many students, commonly known and used measuring tools such as a thermometer or a ruler were obvious examples of instruments. Views on scientific instruments from a few students who have had more exposure to science beyond the first-year chemistry course appeared to include much broader perspectives of instrumentation. Additionally, those more experienced students exhibited deeper understanding of the interconnected nature of science and society as well as the central role instruments have had in such connection.

The evidence from this study, especially from the interview responses provided by the participating students, indicated that many general chemistry students most likely possess a shallow understanding of the nature of science. A student perception of the disconnect between chemistry lecture and laboratory courses were also observed in this study, where some students perceived instruments were only for the laboratory course whereas concepts and math were for the lecture. These observations, combined with the recurring importance of relevancy in student's desire to learn, points at potential areas of improvement both in chemistry laboratory and lecture courses. The chemistry curricula can provide students with more comprehensive views of chemistry by utilizing the history and the role of instruments in science. In addition,

integrating the sociocultural-embedded aspects of science into chemistry curricula can enhance students' interest in the subject, as well as increase their awareness of the nature of science. At the end of the day, scientific knowledge is constructed through observations and inferences made possible with instruments, and science cannot be separated from society we live in. Introducing students to a bigger picture of science and its practice based on the nature of science notions could be an important step towards nurturing students with advanced scientific literacy.

#### **4.5 Conclusion**

The current study utilized a mixed-method approach to explore how general chemistry students view instruments in terms of their roles in science, outside of science, and how these ideas are connected. Students' views on learning about instruments were also assessed through survey and interview activities. The survey results suggested that students generally thought instruments are helpful outside of laboratory settings. However, it is difficult to conclude that the instructional approach which took place in the course that implemented tripartite learning outcomes was the reason behind the improvement, as a significant improvement on the subscale score was also observed among students from other sections. Many students held a positive view on learning about instruments for various reasons such as the usefulness of knowledge and relevancy. The recurring theme of relevancy provides another evidence that the nature of science ideas, presented with tripartite learning outcomes, can be an important instructional method in chemistry education.

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**CHAPTER 5****MEASURING THE IMPACT OF INCORPORATING SYSTEMS THINKING INTO GENERAL CHEMISTRY ON AFFECTIVE COMPONENTS OF STUDENT LEARNING**Jiwoo An,<sup>†</sup> Glen R. Loppnow,<sup>‡</sup> and Thomas A. Holme<sup>†</sup><sup>†</sup> Department of Chemistry, Iowa State University, Ames, Iowa 50011 USA<sup>‡</sup> Department of Chemistry, University of Alberta, Edmonton, AB, Canada T6G 2G2Modified from a manuscript under review in *Canadian Journal of Chemistry***Abstract**

Recently, there has been increased interest in incorporating systems thinking content into various chemistry classrooms. One promise of systems thinking is that students will be able to connect typical chemistry concepts learned in lectures with real-life situations through context-rich instruction. Such experiences may impact affective factors related to learning such as motivation and attitude of students. These factors have often revealed negative orientation for students in chemistry courses, where the majority of students are externally motivated while intrinsic motivation is positively correlated with students' course performance. In order to assess whether a systems thinking instructional approach can make a positive impact on affective areas of learning, student motivation and attitude levels were measured using a modified Situational Motivation Scale (SIMS) and the short version of Attitude towards the Subject of Chemistry Inventory (ASCIv2) in a general chemistry course. Pre- and post-survey data suggest that a first-semester chemistry course that incorporates systems thinking does not induce significant positive changes in students' motivation. End of the semester motivation and attitude levels were correlated with students' ACS exam scores, where students with higher levels of intrinsic motivation showed better performance on the ACS exam. While the results obtained in this study

were not optimistic, they suggest several areas of study within systems thinking instruction as potential areas to improve both instruction and student reception of the systems thinking components of instruction.

## 5.1 Introduction

There are many factors that influence student learning of science, including natural aptitude,<sup>1,2</sup> previous experiences,<sup>1,2</sup> mathematical abilities,<sup>3</sup> motivation,<sup>3-6</sup> self-regulation,<sup>7</sup> self-concept,<sup>8,9</sup> attitude,<sup>10</sup> beliefs, and classroom context.<sup>5,6</sup> While cognitive factors such as aptitude and mathematical abilities may appear to be obvious predictors for student success in science courses, researchers have continuously argued that affective domains (e.g., motivation and attitude) must not be overlooked in understanding student achievement.<sup>11,12</sup> In fact, some types of motivation (i.e., intrinsic) have been identified to lead to intellectual and emotional fulfillment,<sup>13,14</sup> showing correlations to higher conceptual understanding, challenge-seeking behaviors, and perseverance in difficult tasks.<sup>14</sup> Furthermore, the affective domain is intimately connected to human cognition and behaviors, as recognized psychological theories.<sup>15</sup> Understanding the complex relationships among these factors and how they influence student learning is important for both instructors and students.

### *Theories of Motivation Measurement*

Several theoretical frameworks, such as social-cognitive theory (SCT), self-determination theory (SDT), and expectancy-value theory, have been applied to the study of motivation and attitude in science education research. Bandura's social-cognitive theory states that cognitive processes influence motivational and learning processes, where components such as personal characteristics, environmental contexts, behaviors and self-regulation are interrelated.<sup>16</sup> In this

framework, motivation is seen as an internal state which drives and maintains “goal-oriented behaviors”, such as asking questions, class participation, and studying.<sup>17</sup> Because of the multicomponent characteristic of SCT, motivation instruments based on the SCT framework often contain several variables. Examples include intrinsic motivation, extrinsic motivation, self-regulation and self-efficacy. Definitions of the motivation terms are covered in the following section.

Self-determination theory (SDT) states that human behaviors are a result of different types of motivation, driven by a sense of choice or determination.<sup>18</sup> This theory views motivation as a multidimensional concept, with different types of motivation.<sup>19</sup> Thus, motivation is broken down into three categories based on the degree of autonomous and controlled nature of behaviors: Intrinsic motivation, extrinsic motivation, and amotivation. Intrinsic motivation refers to engaging in an activity to feel pleasure and satisfaction. Individuals with intrinsic motivation often show enhanced conceptual understanding and problem-solving skills,<sup>5,18</sup> as well as more persistence and regulation in conceptual learning.<sup>5,20</sup> Extrinsic motivation refers to behaviors motivated by external factors beyond the inherent pleasure of activities. Four types of extrinsic motivation have been identified, namely, integrated regulation, identified regulation, introjected regulation, and external regulation, listed in order of decreasing self-determination.<sup>21</sup> In other words, there are levels to which external factors are internalized, and these terms are listed from more internalized to less.<sup>18,19,22</sup> Integrated regulation describes behaviors that are fully self-directed but still based on internalized values, whereas behaviors are perceived to be chosen by individuals due to the internalized importance with identified regulation. External regulation is driven by the external rewards or to avoid negative consequences, hence it is the least autonomous form of extrinsic motivation. Introjected regulation lies between external regulation

and identified regulation, where people start to identify reasons for their behaviors to be internalized.<sup>18,19,22</sup> The last category of motivation is amotivation, which describes engaging in behaviors out of obligation with no inherent interest.<sup>22</sup>

Expectancy-value theory<sup>23</sup> claims that people's beliefs on their potential achievement and how they value an activity can explain their choice, perseverance and performance.<sup>24</sup> This is a complex model encompassing areas such as one's interpretation of previous experience, cultural background, goals, previous achievements, and belief on their ability. These areas are interrelated and interact to ultimately affect one's choices related to their achievement. Beliefs about one's ability to perform (expectancy), beliefs about the task importance (value), and emotional reactions to the task (affective) are the three motivational components proposed by Pintrich et al. based on the expectancy-value theory.<sup>25-27</sup> The expectancy component involves students believing that they are able to perform a task, and this component has been linked to the use of learning effort, use of cognitive strategies, and metacognition.<sup>28</sup> The value component essentially indicates students' goals and reasoning for engaging in a task. In general, students with a mastery goal and those who consider the task important engage in more metacognition or cognitive strategies.<sup>23</sup> Lastly, the affective motivational component takes into account students' feelings towards a task. Even though the relationship is not as clear as the other two motivational components, emotional states such as anxiety can influence learning.<sup>27,29</sup> For example, highly anxious students may show the same amount of effort in completing a task, but they often employ ineffective learning strategies and use less metacognitive strategies compared to those students with low anxiety.<sup>30</sup> These motivational components based on the expectancy-value theory are important in learning, especially in the fields of science, technology, engineering, and mathematics (STEM).<sup>31</sup>

### *Scales Measuring Motivation*

There are several reported instruments measuring student motivation in science courses at various levels of education, employing different theories discussed in the previous section. Motivated Strategies for Learning Questionnaire (MSLQ) is an 81-item instrument based on expectancy-value theory to measure university students' motivation levels in using various learning strategies.<sup>27,32</sup> This self-report instrument was employed extensively in measuring motivation of middle school level<sup>27</sup> and college level students<sup>25,26,32</sup> to study how motivational components are related to students' self-regulated learning (i.e., use of various learning strategies).

The Science Motivation Questionnaire-II (SMQ-II) was reported in 2011 and is based on SCT. It uses five items each to measure five aspects of motivation (intrinsic motivation, self-determination, self-efficacy, career motivation, and grade motivation) of college students.<sup>33</sup> The SMQ-II instrument was tested with science and non-science major students in introductory biology courses with successful reliability and validity results. The same authors later produced and tested discipline-specific versions of SMQ-II for chemistry, physics, and biology.<sup>34</sup> The Organic Chemistry Motivation Survey (OCMS) was derived from SMQ-II to measure motivation of organic chemistry students specifically.<sup>34</sup>

Several other motivation measurement scales have been reported. The Students' Motivation Towards Science Learning (SMTSL) measures six different factors of motivation (self-efficacy, active learning strategies, science learning value, performance goal, achievement goal, and learning environment stimulation).<sup>35</sup> The Multidimensional Motivation Instruments (MMI), examines the relationship between students' motivation and the learning environment.<sup>36</sup> The Academic Motivation Scale (AMS)<sup>22</sup> was initially developed to measure three different

types of intrinsic motivation (to know, to accomplish, to experience) and extrinsic motivation (identified regulation, introjected regulation, external regulation), as well as amotivation using 28 items.<sup>22</sup> Liu et al. recently modified the existing AMS to measure motivation towards chemistry (AMS-Chemistry).<sup>19</sup>

An instrument that is similar to AMS is the Situational Motivation Scale (SIMS). Developed by Guay et al.<sup>37</sup> in 2000, the SIMS is a 16-item instrument based on SDT and measures intrinsic motivation, two types of extrinsic motivation (identified and external regulations), and amotivation. Initially, the SIMS was not developed for a specific discipline or population, but the scale has been applied in other fields since its development, predominantly in physical education.<sup>38-44</sup> For example, Standage et al. applied the SIMS to evaluate the relationship between middle school students' task orientations and situational motivation in physical education class.<sup>38</sup> The same authors later studied relation of situational motivation and participation in physical activity in different groups of sample population using the SIMS.<sup>39</sup> A recent study applied the Norwegian version of the SIMS to understand adolescent's learning and motivation in physical education courses.<sup>40</sup> Taylor and Ntoumanis examined the relationship between teacher's self-determination and the use of teaching strategies such as autonomy support, structure, and involvement in physical education.<sup>41</sup> Another application of the SIMS explored how different types of motivation are correlated with student satisfaction in distance education.<sup>45</sup>

### *Motivation in Chemistry*

The affective domain is difficult to measure despite being a crucial component of learning, because aspects such as motivation or attitude are not directly observable.<sup>34</sup> Even with this difficulty, many studies have measured motivation in an attempt to predict students' course

performance in general chemistry and organic chemistry courses.<sup>1,34</sup> For example, the 81-item MSLQ has been used in a general chemistry course taught with a peer-led, active learning pedagogical approach to identify different learning strategies used by students.<sup>46,47</sup> In a study reported by Ferrell and Barbera, scales measuring several motivational constructs (interest, self-efficacy, effort beliefs) were adapted and modified to be reliably used in general chemistry context.<sup>1</sup> They found that chemistry majors exhibited higher levels of the three constructs compared to non-chemistry majors. A modified scale was also used to connect the three constructs to course performance, suggesting that the end of the semester measure of self-efficacy was the strongest predictor of the course grade.<sup>48</sup> Orvis et al. used the AMS to measure what types of academic motivation college chemistry students possess and found that undergraduate chemistry students primarily display external motivation.<sup>49</sup> The measurement using AMS-Chemistry version modified by Liu et al. showed that students were on average motivated extrinsically, and intrinsic motivation subscales were positively correlated with students' course performance.<sup>19</sup> Another study attempted to measure the effect of using flipped classroom approach in organic chemistry on motivation by AMS-Chemistry, finding that intrinsic motivation was positively correlated with students' academic achievement.<sup>50</sup> An implementation of OCMS to measure motivation in an organic chemistry course showed that different areas of motivation were correlated differently with students' course performance.<sup>34</sup> The use of SIMS has not been reported in chemistry courses, but the fact that the SIMS has only 16 items shows promise for a more rapid tool for measuring motivation.

#### *Attitude Measurement*

Attitude measurement has been explored often in chemistry education research<sup>51</sup> using multiple instruments to assess different constructs of attitude. These instruments include

Chemistry Expectation Survey (CHEMX, 47 items),<sup>52</sup> Chemistry Attitudes and Experiences Questionnaire (CAEQ, 69 items),<sup>53</sup> Colorado Learning Attitudes about Science Survey (CLASS, 50 items),<sup>54,55</sup> and Attitude toward the Subject of Chemistry (ASCI, 20 items).<sup>56</sup> The 20-item ASCI was revised by Xu and Lewis to include only 8 items, resulting in a short but reliable instrument, ASCIv2, to measure two aspects of student attitudes.<sup>57</sup> The ASCIv2 was included in this study for two reasons: the 8-item version provides a quick way to assess student attitudes without making surveys overly long, and the inclusion of the ASCIv2 makes it possible to study potential relationships among types of motivation and attitudes in the general chemistry context.

### Current Study

In this study, the prior experience in measuring motivation and student attitudes in chemistry is leveraged to understand how a general chemistry course that was taught with the incorporation of systems thinking concepts<sup>58,59</sup> influences student affective engagement with the field. Systems thinking represents an emerging curricular philosophy in chemistry education that has begun to find curricular implementations, as evidenced by a recent special issue of the *Journal of Chemical Education*. The central ideal for incorporating systems thinking in chemistry courses is to connect concepts to rich contexts,<sup>60</sup> fostering greater awareness of the role of chemistry in understanding earth and societal systems<sup>61</sup> and enhancing scientific literacy.<sup>62</sup> This approach enables students to look outside of the concepts typically taught in large lecture courses, realizing that there are countless real-life connections to be made with chemistry. Reported use of systems thinking broadly includes connecting general and organic chemistry topics to ideas of climate,<sup>58,60</sup> global sustainability,<sup>61</sup> and environment and human health.<sup>59,63</sup> The SIMS instrument for measuring motivation<sup>37</sup> was applied for the first time in chemistry using this classroom context. In addition, the ASCIv2<sup>57</sup> was used to assess student perceptions of the



cognitive and affective domains of chemistry. Changes in students' motivation and attitudes between the start and the end of the semester were examined. Research questions this study sought to address are as follows:

1. What are the assessment characteristics of the SIMS tool when used to measure motivation in general chemistry?
2. How do the 4 types of motivation and 2 domains of attitude change after a semester of general chemistry course that incorporates systems thinking instruction?
3. How is student chemistry content knowledge, as measured by an end-of-semester ACS Exam correlated with each type and domain of motivation and attitude?
4. How is motivation correlated to students' attitudes towards chemistry as a subject?

## 5.2 Methods

### *Research Context*

Previous motivation and attitude studies have often found students in chemistry courses to be externally motivated.<sup>19,49</sup> Considering the recent emergence of systems thinking in chemistry education and the importance of motivation and attitudes in student learning, it was of interest to examine whether this curricular approach could produce changes in students' motivation and attitudes that have been found to have a positive effect on student learning.<sup>6,34,49</sup>

The general chemistry class where this study took place met three times a week with the instructor for a 50-min lecture in Fall 2018 semester. Context related to systems thinking was incorporated regularly, though often briefly, throughout the semester in these lectures as previously reported.<sup>58,59</sup> Typically, for mid-term exams with 25 questions, 3-4 would include the systems thinking components from the course. A teaching assistant-led, small-group, 50-min recitation session was held once a week. A short on-line quiz was offered three times a semester to encourage students to think about chemistry through the lens of systems thinking. Throughout the semester, three one-hour exams were held that included 1 to 4 systems thinking-related

questions. The final exam used an ACS Exam which therefore did not include any explicit connections to systems thinking.

### *Data Collection*

Before data collection, the study was ruled exempt by the Institutional Review Board (IRB, Appendix E). Two separate sections of the course were taught by the same instructor with systems thinking instructional approach and were included in the study. The “pre-semester” surveys were available for six days during the first week of the semester, and the “post-semester” surveys were available for ten days before the final exam. Both surveys were available for access through the course learning management system (LMS) page. Surveys were part of a system that required students to complete roughly two-thirds of assignments in an on-line component of the course. Thus, participation in both surveys was not explicitly required, though students received points towards the on-line materials grouping for completing both surveys. The pre- and post-survey items were identical, where 16 SIMS items and 8 ASCIv2 items were present. The SIMS instruction was changed from “Why are you currently engaged in this activity?”<sup>37</sup> to “Please choose the response for each statement that best describes how much the statement reflects the reason you are currently engaged in this class (CHEM 177)”. A full version of the SIMS used in this study can be found in Table D1 of Appendix D. The response options ranged from 1 to 7, describing “Corresponds not at all” to “Corresponds exactly”, respectively. The item order for both pre- and post-survey were kept the same as the original SIMS. As the ASCIv2 uses a semantic differential scale, students were directed to choose a number (1-7) in between two words.

Student demographic information was not collected with individual survey responses. However, the course was comprised of 752 students at the beginning of the course with approximately 67.6% freshman, 22.5% sophomore, 7.8% junior, and 2.1% senior-level. Enrollment at the end of the semester was 678. Of these students, 36.0% were declared engineering majors (i.e., civil, chemical, etc.), 22.1% were biology or genetics majors, and the remaining fraction was comprised of various physical and social science areas such as kinesiology, animal science, biochemistry, and psychology. Only 18 students who were registered for the course at the start of the semester were declared chemistry majors, and this number did not change at the end of the semester.

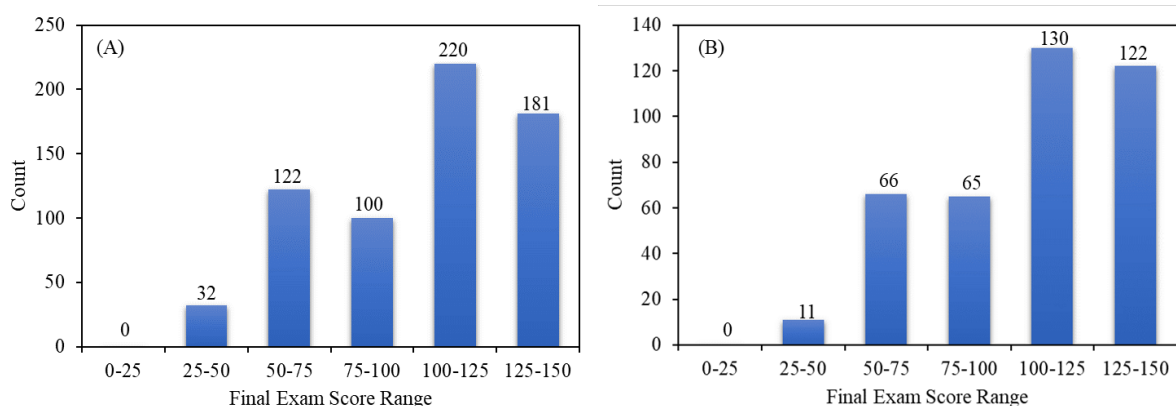
### *Data Analysis*

For this study, matched responses were required. The matching of pre- and post- surveys invoked student IDs from the LMS before the data was anonymized. In addition, any responses that were missing answers to one or more items or providing the same response to all items for each survey (SIMS and ASCIv2) were removed from the overall data set, i.e. listwise deletion.<sup>64</sup> The final number of student responses remaining for subsequent data analysis was 394. All data analysis was completed using R/RStudio software.

Points obtained by students on the final exam were used as a measure of proficiency in this study. Points were assigned from performance on an ACS Exam, where the national percentiles were converted into points commensurate with having the final worth 150 points out of a possible 600 points in the course. The 50% percentile of the ACS exam is roughly equivalent to the middle of the “C” score range for the final.

The number of students enrolled in the two sections of CHEM177 course at the end of the semester in this study was 678 (approximately 10% decrease in enrollment from  $N=752$  in August). Of these students, 23 scores were omitted from the average score calculation as these students did not take the final exam. The average final exam score of 655 students was 102.5. The average final exam score for the population of students who were included in further statistical analyses ( $n=394$ ) was 105.5. This sample number represents approximately 60% of the whole class population.

An independent  $t$ -test was performed in order to assess whether the sample number presented a comparable score of the ACS exam to the entire class population. The results indicated that the two average exam scores did not possess any statistically significant difference ( $p > 0.05$ ). The score distributions of each population are shown in Figure 5.1.



**Figure 5.1.** Final exam score distribution for (A) all students who took the final exam ( $n=655$ ,  $\mu=102.5$ ) and (B) sample population included in this study ( $n=394$ ,  $\mu=105.5$ ).

While the ASCIv2 has been used and validated in numerous studies, this is the first known report of the use of the SIMS in chemistry context. Thus, validation was completed with confirmatory factor analysis (CFA). Reliability of each factor was confirmed with Cronbach's  $\alpha$ . Paired  $t$ -tests were performed to evaluate any difference in students' attitudes and motivation between the pre-semester and post-semester survey data. Bonferroni correction was applied to

adjust the  $p$ -value to  $\alpha = 0.0125$  ( $k = 4$ ) and  $\alpha = 0.025$  ( $k=2$ ) for the SIMS and ASCIv2 results, respectively. Effect size (Cohen's  $d$ ) was calculated for each t-test group to assess the magnitude of any observed differences. A widely accepted range<sup>65</sup> for Cohen's  $d$  is small (0.20), medium (0.50), and large (0.80). To assess how each type of motivation and the two domains of attitude are related to students' performance on an ACS exam, multiple regression analyses were performed. All model assumptions were checked prior to the multiple regression analysis, and this process is described in detail in the following section.

### 5.3 Results

#### *Validation of SIMS*

While SIMS have been applied and validated in other areas, it has not been employed to measure students' motivation in chemistry courses. Therefore, validation of the instrument in college chemistry setting was necessary (RQ1). A confirmatory factor analysis (CFA) was performed to evaluate how well the original model fit the measured variables in this study using the pre-survey data. In CFA, two types of fit indices, namely, absolute and incremental, are commonly used to evaluate the fitness of model.<sup>1</sup> Absolute fit indices estimate the goodness of fit of an *a priori* model to the data, and they include chi-square ( $\chi^2$ ), root mean squared error of approximation (RMSEA), and standardized root mean squared residual (SRMR). The  $\chi^2$  statistics are reported but not a reliable measure of acceptable model fit, due to its sensitive nature to sample size yielding significant  $p$ -values with large sample sizes.<sup>66</sup> The RMSEA values below 0.06 are deemed good fit and values below 0.08 are considered acceptable.<sup>67</sup> The SRMR refers to a "badness of fit", where an SRMR value below 0.05 is considered a good fit and below 0.10 is acceptable.<sup>67</sup> Incremental indices include comparative fit index (CFI) and Tucker Lewis

index (TLI), which evaluate the model fit based on the difference between the proposed model and the data.<sup>1</sup> The acceptable CFI and TLI values that indicate a good fit of a model are  $\geq 0.95$  and  $\geq 0.90$ , respectively,<sup>67</sup> and at least one of the two values is reported as they are highly correlated. In this study, CFI values are reported.

The original model proposed by Guay et al. had four latent variables, each latent variable containing four items.<sup>37</sup> The initial CFA analysis revealed that the *a priori* model did not adequately fit the data ( $\chi^2 (98, N=394) = 412.21, p < 0.001, CFI = 0.899, RMSEA = 0.091, SRMR = 0.080$ ). This phenomenon was also observed in other studies and all reported that Guay et al.'s original 4-factor model for the 16 SIMS items did not fit the collected data.<sup>38-40</sup> Common problems authors found in these studies were the high residual correlation between items 10 ("By personal decision") and 11 ("Because I don't have any choice") as well as the cross-loading of these items onto several factors.

Based on these reports, both residual correlations and modification indices (MI) were investigated for the CFA. Similar efforts have been reported previously in the field of chemistry education research<sup>1</sup> as well as in other fields where SIMS have been applied to measure situational motivation.<sup>38-40,42</sup> The residual correlation value between the items 10 and 11 (-0.408) indicated that these items may be contributing to the model misfit. Further examination revealed that the top MI's were for the items 10 and 11, suggesting that they may be involved in covariances not explained by the model.

As discussed in Standage and Treasure,<sup>38</sup> removal of these items was considered based on the theoretical distinction among the types of motivations that the SIMS was developed to assess. Removal of only one item (either item 10 or 11) from the model did not yield acceptable CFA parameters. The results of CFA without item 10, without item 11, and without both items are

shown in Table 5.1. Removal of both items 10 and 11 resulted in satisfactory CFA indices ( $\chi^2$  (71,  $N=394$ ) = 201.45,  $p < 0.001$ , CFI = 0.950, RMSEA = 0.069, SRMR = 0.049). Based on these data, a 14-item SIMS, without items 10 and 11 was adopted in this study to explore general chemistry students' situational motivation.

**Table 5.1.** Confirmatory factor analysis results of the 4 models applied to the SIMS.

Model	$\chi^2$ (df, N)	$p$ -value	CFI	RMSEA (90% Confidence Level)	SRMR
Original 16-item model	412.21 (98, 394)	< 0.001	0.899	0.091 (0.082, 0.100)	0.080
15-item model without item 10	289.31 (84, 394)	< 0.001	0.928	0.079 (0.069, 0.089)	0.067
15-item model without item 11	296.75 (84, 394)	< 0.001	0.926	0.080 (0.071, 0.091)	0.063
14-item model without items 10 and 11	201.45 (71, 394)	< 0.001	0.950	0.069 (0.058, 0.080)	0.049

Reliability of the SIMS subscales was assessed by Cronbach's  $\alpha$  coefficients. Both the pre-survey and the post-survey subscales presented satisfactory internal consistency. In the order of intrinsic motivation, identified regulation, external regulation, and amotivation, Cronbach's  $\alpha$  coefficients were 0.90, 0.80, 0.79, and 0.78, for the pre-survey, and 0.90, 0.85, 0.78, and 0.83 for the post-survey. These values were all above the commonly accepted cutoff of 0.70 to consider the internal consistency of the four SIMS subscales acceptable.

#### *Paired t-test & effect size*

To estimate how student motivation and attitude change over the first term of general chemistry, a paired  $t$ -test of the SIMS and ASCIv2 data was performed on each type of motivation as well as the two domains of attitude (cognitive and affective). Both instruments utilize a 7-response scale, meaning the closer the mean value is to 7 the higher the level of motivation or attitude it represents. Table 5.2 shows mean value of each type of motivation as

well as the two domains of the attitude measured for both pre- and post-survey. Students reported mid-level intrinsic motivation in the beginning of the semester, and its mean value decreased for the post-survey. A paired *t*-test showed that the difference ( $\mu_d = 0.39$ ) is statistically significant with a *p*-value below 0.0001. Cohen's *d* for the change in intrinsic motivation is 0.254, which represents a small effect size. A similar trend was observed for identified regulation, where the mean value decreased for post-survey and a statistically significant *p*-value and a small effect size (Cohen's *d* = 0.323). Post-survey means for external regulation and amotivation increased compared to those of pre-survey, indicating an increase in the extent to which students were externally motivated (specifically, external regulation) and amotivated in the studied chemistry course at the end of the semester. While all *t*-test results were significant, the change in external regulation scores was negligible ( $d < 0.2$ ), and the amotivation score change showed a small effect size ( $d = 0.264$ ).

**Table 5.2.** Descriptive statistics, paired *t*-test results, and effect sizes of the four types of motivation measured with SIMS.

Instrument	Type <sup>a</sup>	Mean <sup>b</sup> (pre-survey)	Mean <sup>b</sup> (post-survey)	<i>p</i> -value	Cohen's <i>d</i>
SIMS	Intrinsic	3.90	3.51	< 0.0001 <sup>c</sup>	0.254
	Identified Regulation	5.12	4.64	< 0.0001 <sup>c</sup>	0.323
	External Regulation	5.28	5.49	< 0.0001 <sup>c</sup>	0.137
	Amotivation	2.17	2.54	< 0.0001 <sup>c</sup>	0.264
ASCIv2	Cognitive	3.03	2.95	0.021 <sup>d</sup>	0.059
	Affective	4.12	3.87	< 0.0001 <sup>d</sup>	0.156

<sup>a</sup> All scales from 1 to 7; 1 indicates low and 7 indicates high level of each motivation type and attitude domain.

<sup>b</sup> N=394.

<sup>c</sup> Paired *t*-test; *p*-value at 95% confidence level; all *p*-values are statistically significant after the Bonferroni correction for  $k=4$  ( $\alpha = 0.0125$ ).

<sup>d</sup> Paired *t*-test; *p*-value at 95% confidence level; both *p*-values are statistically significant after the Bonferroni correction for  $k=2$  ( $\alpha = 0.025$ ).

The cognitive domain factor of the ASCIv2 assesses whether students think chemistry is hard/easy, complicated/simple, confusing/clear, and challenging/unchallenging and has been



referred to as “intellectual accessibility”.<sup>57</sup> The initial score of 3.03 indicates that students tended to find chemistry a hard, complicated, confusing, and challenging subject as the course began. The end of the semester score for this factor was 2.95, where the score decreased by 0.08, with the  $p$ -value of 0.021 ( $\alpha < 0.025$ ,  $k = 2$ ). Based on the effect size, the change in the intellectual accessibility of chemistry was in a negative direction but was not significant and negligible. The affective domain or “emotional satisfaction”<sup>57</sup> showed a similar shift in mean values before and after the semester with a decrease of 0.25 in mean value. Similar to the cognitive domain,  $t$ -test revealed a statistically significant difference while Cohen’s  $d$  indicated a negligible change.

### *Multiple Regression*

Multiple regression is a valuable analysis technique in assessing how various independent variables are associated with one dependent variable. The results from this analysis can also be used to predict the value of the dependent variable based on the impact of each independent variable included in the regression model. A general regression equation is shown in equation 1, where  $Y$  refers to the predicted value of the dependent variable, and  $X_1$  through  $X_p$  represent each distinct independent variable. The term  $B_0$  is the value of  $Y$  when all independent variables ( $X_1 \dots X_p$ ) are zero, and  $B_1$  through  $B_p$  represent the estimated regression coefficients. The regression model 1 had the ACS exam score as the dependent variable ( $Y$ ), and the four types of motivation as the independent variables ( $X_1$  through  $X_4$ ).

$$Y = B_0 + B_1X_1 + B_2X_2 + \dots + B_pX_p + e \quad \text{Eq. 1}$$

One of the research questions considered through this study was how each type of motivation is associated with students’ performance on the ACS exam. Multiple regression allows us to gain an idea of how each type of motivation may be related to final ACS exam

scores by including the four types of motivation measured with the SIMS as independent variables. Before any regression model was applied, all of the necessary assumptions for multiple regression analysis were checked. These assumptions are normal distribution of errors between observed and predicted values (normality), equal distribution of residuals (homoscedasticity), a linear relationship between the independent and dependent variables (linearity), and absence of significant correlation between the independent variables (multicollinearity).

The normality assumption is often checked with the normal Q-Q plot, as this plot provides a quick and easy assessment of the residual normality.<sup>68</sup> With 394 samples, a linear Q-Q plot was observed with a slight deviation at the tails. After consulting with the statistics consulting group at the authors' institution and a review of literatures,<sup>68-72</sup> it was concluded that even with the slight heavy-tailed residuals, the study contained high sample numbers for the multiple regression analysis to be robust. Homoscedasticity and linearity were checked by the visual examination of the residuals versus predicted value plot.<sup>73</sup> The ideal distribution of residuals versus predicted values is a random scatter without any observable pattern, which results in a straight, horizontal line across the plot. A straight line with randomly scattered points were observed, meeting the assumptions of homoscedasticity and linearity. Lastly, the absence of multicollinearity is evaluated by variance inflation factor (VIF). This test detects possible inflation of the variance in the regression estimates, where 1 represents no correlation between the predictors, values between 1-5 represent moderate correlation but no abnormal variance inflation, and values above 5 indicate high correlations between predictors. The VIF results ranged from 1.133 to 2.141, indicating that multicollinearity was not present in our model.

Pre-semester SIMS results and the course's first hour-exam scores were used for a multiple regression analysis in order to assess whether the initial motivation levels students possess have any predictive power to their performance early in the semester. The first hour-exam of the course was given in the fourth week of the semester. The exam was comprised of multiple-choice items (90 pts) and a few short-answer questions (10 pts), worth 100 points total. As seen in Table 5.3, the initial levels of motivation students possessed when the semester began were not great predictors of their first exam performance. Amotivation was the only significant predicting factor in this model ( $p < 0.05$ ). The first exam of the semester often contains concept many students learn in high school chemistry, and it is possible that the level of prior knowledge in some students influenced their performance regardless of their motivation types or levels. In addition, their motivation levels could have changed in the first three weeks of the semester, especially if students were unfamiliar with the subject before they started the course. This lack of predictive power of the pre-semester motivation levels on the first exam performances may be explained by students' tendency to overestimate their abilities at the beginning of the semester, similar to what was observed in the study measuring students' awareness of their problem solving skills through metacognitive activities inventory (MCAI).<sup>74</sup>

**Table 5.3.** Multiple regression results representing Model 1 where  $Y$  = First hour-exam score,  $X_1$  = intrinsic motivation,  $X_2$  = identified regulation,  $X_3$  = external regulation, and  $X_4$  = amotivation.

Model: Pre-Semester	Unstandardized Coefficients		Standardized Coefficients	$p$ -value <sup>a</sup>
	B	Std. Error	Beta ( $\beta$ )	
(Intercept)	69.647	4.998	0.000	2e-16***
Intrinsic Motivation	0.733	0.688	0.075	0.2871
Identified Regulation	-0.099	0.742	-0.009	0.8944
External Regulation	0.515	0.524	0.053	0.3260
Amotivation	-1.460	0.740	-0.114	0.0491*

<sup>a</sup> Significance where \* =  $p < 0.05$ , \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$ .

The multiple regression results of post-semester SIMS measurement are shown in Table 5.4. As can be seen in Table 5.4, intrinsic motivation ( $\beta = 0.196$ ,  $p < 0.01$ ), external regulation ( $\beta$

= -0.104,  $p < 0.05$ ), and amotivation ( $\beta = -0.145$ ,  $p < 0.05$ ) had significant standardized coefficients. The standardized coefficient of the identified regulation ( $\beta = 0.075$ ,  $p = 0.2703$ ) did not show significance. Nonetheless,  $\beta$  values show that intrinsic motivation and external regulation were positively related to the exam scores, whereas identified regulation and amotivation were negatively related to the exam scores. Figure 5.2 visually illustrates the relationships between each type of motivation and the final exam score in the course. Intrinsic motivation (A) score has a clear, positive correlation to higher exam score, and identified regulation (B) shows a similar trend but to a lesser extent. External regulation (C) shows a negative correlation, and amotivation (D) score clearly shows a negative relationship with the exam performance. Both multiple regression results and the correlation plots suggest that students with more intrinsically-oriented motivation are predicted to perform better on the ACS exam at the end of the semester compared to those who are extrinsically motivated (less self-determined type) or amotivated.

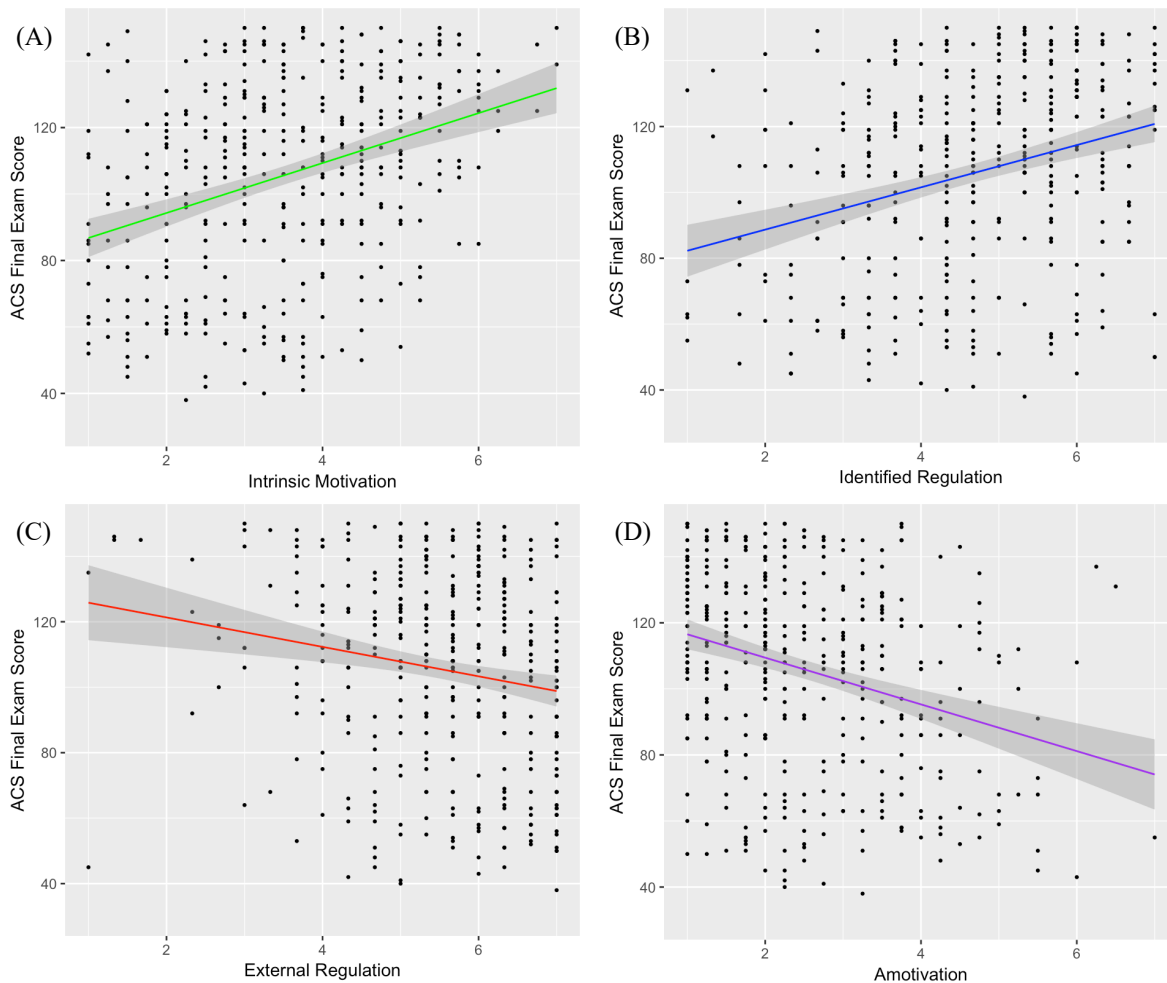
**Table 5.4.** Multiple regression results representing Model 1 where  $Y =$  ACS exam score,  $X_1 =$  intrinsic motivation,  $X_2 =$  identified regulation,  $X_3 =$  external regulation, and  $X_4 =$  amotivation at the end of the semester.

Model 1	Unstandardized Coefficients		Standardized Coefficients	$p$ -value <sup>a</sup>
	B	Std. Error	Beta ( $\beta$ )	
(Intercept)	106.371	11.141	0.000	2e-16***
Intrinsic Motivation	4.265	1.431	0.196	0.0031**
Identified Regulation	1.615	1.463	0.075	0.2703
External Regulation	-2.634	1.244	-0.104	0.0348*
Amotivation	-3.515	1.413	-0.145	0.0132*

<sup>a</sup> Significance where \* =  $p < 0.05$ , \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$ .

Overall, the four predictors accounted for 14.4% of the variance ( $R^2_{\text{adjusted}} = 0.144$ ,  $F(4, 389) = 17.52$ ,  $p < 0.001$ ). Note that a low  $R^2$  value does not mean the relationships found in the model are insignificant.<sup>75</sup> This regression model does provide more evidence of different factors

being involved in student learning besides motivation. Nonetheless, the four types of motivation measured with the SIMS are related to how students perform on the ACS exam, especially intrinsic motivation.



**Figure 5.2.** Scatter plot of each type of motivation versus the ACS final exam score, where (A) intrinsic motivation, (B) identified regulation, (C) external regulation, and (D) amotivation. Linear regression line with 95% confidence level (shaded area) is shown in each plot.

The same process of multiple regression analysis was applied to the ASCIv2 data. Model 2 included cognitive and affective domains of attitude as independent variables ( $X_1$  and  $X_2$ , respectively) and the ACS exam score as the dependent variable ( $Y$ ). The four assumptions of multiple regression were checked and met, and the regression results are shown in Table 5.5.

Both the cognitive and the affective domains were found to be significantly associated with

students' performance on the ACS exam ( $p < 0.001$  for both). Higher levels of cognitive and affective domains of attitude were positively correlated with the exam scores, indicating that students who feel chemistry is more intellectually accessible and emotionally satisfying showed higher achievement on the standardized ACS exam. Once again, the conclusion of how students feel cognitively and affectively about chemistry is related to their performance, but those are not the only factors influencing students' learning of chemistry.

**Table 5.5.** Multiple regression results representing Model 2 where  $Y =$  ACS exam score,  $X_1 =$  cognitive domain and  $X_2 =$  affective domain at the end of the semester.

Model 2	Unstandardized Coefficients		Standardized Coefficients	$p$ -value <sup>a</sup>
	B	Std. Error	Beta ( $\beta$ )	
(Intercept)	69.759	4.302	0.000	2e-16***
Cognitive	7.016	1.645	0.275	2.51e-05***
Affective	3.877	1.439	0.174	0.00738**

<sup>a</sup> Significance where \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$ .

## 5.4 Discussion

Given the instructional goal of adding systems thinking content to the course was at least partially made to enhance student motivation to learn chemistry, the results of this study are somewhat disappointing. At least for the current implementation of systems thinking, with only a modest percentage of the course was dedicated to this approach, the changes in student motivation to study chemistry are small to negligible and towards lower levels of intrinsic motivation. A higher tendency to be amotivated at the end of the semester is also observed, which is not a desired outcome either. It is important to realize that these results are similar to the previous reports of student motivation in chemistry courses taught without systems thinking instructions. The study using AMS-Chemistry found that students were mostly extrinsically motivated toward the first-term general chemistry course they were enrolled in, and students' amotivation increased slightly towards the end of the semester.<sup>19</sup> Another report of AMS in

chemistry course concluded that almost 60% of the students in general chemistry course are extrinsically motivated, and below 5% of the students in the course showed intrinsic motivation.<sup>49</sup>

To consider the utility of the SIMS model for measuring motivation in chemistry courses further, it is valuable to consider the multiple regression model 1, which suggested that while the SIMS measures four types of motivation, the values obtained for them do not explain the majority of the variance in student content knowledge at the end of the course (Table 5.4). Interestingly, intrinsic motivation is positively correlated with the ACS exam scores, while amotivation is negatively correlated with the exam scores. This positive correlation between exam grades and intrinsic motivation has been reported before.<sup>19</sup> A less self-determined version of extrinsic motivation also appeared to be a significant predictor of the exam scores with negative correlation. This study supports the previous reports about motivation in chemistry courses, but further the findings by identifying types of motivations to the standardized ACS exam scores.

Turning to the ASCIv2, the cognitive factor of this instrument assesses how intellectually accessible the subject of chemistry feels to students. Thus, higher scores indicate that students feel chemistry is easier, simpler, clearer, and less challenging. Based on the regression model, an increased score of one for the cognitive factor on the ASCIv2 (while the affective score is held constant) is expected to increase the points scored on the final exam by 7 points. Based on the grading system used in the course, this difference corresponds to roughly two addition items correct on the ACS exam. The *p*-value ( $< 0.0001$ ) suggests that the cognitive domain of affect is a meaningful predictor variable in the regression model. While the causality direction of this observation is not known, if students feel chemistry is more intellectually accessible at the end of

the semester it may have a positive effect on their course performance as measured by an externally constructed ACS exam. The emotional satisfaction factor score of the ASCIv2 also shows a positive correlation with performance on the ACS exam. Thus, this study has results that reflect prior reports that emphasize the importance of affective factor in learning.<sup>15,47,48</sup> For example, Chan and Bauer found that chemistry students in the high affective group possessed characteristics of intrinsic motivation (i.e., initiating learning, challenge seeking behaviors), and the high affective level was correlated to high achievement.<sup>47</sup>

These results were obtained in a course that included a systems thinking curricular approach, explicitly connecting traditional chemistry concepts to larger systems throughout the course. The results reported here, however, were similar to the previously published reports of general students' motivation and attitude, where students are mostly extrinsically motivated. Thus, the current study does not support the hypothesis that a systems thinking approach will induce a differential positive impact on students' intrinsic motivation, relative to more traditional approaches. Reasons can be postulated to understand these study results. First, this course is taken by students from a wide range of interest, major, background, and career goals and therefore finding connections to "bigger picture" topics used to highlight systems thinking faces challenges in terms of identifying universal student interest. Second, the incorporation of systems thinking themes is notably different than what most students have experienced in prior chemistry courses. As a result, students may form negative impressions based on the fact that the added content does not align well with their expectations for what a chemistry course "should be". Such reactions could be reflected in motivation and attitude measures. It is worth noting that some fraction of students expressed their appreciation through other venues not included in the measures reported here for being able to connect chemistry to concepts of everyday life.



Nevertheless, the quantitative data from the SIMS and ASCIv2 appear to suggest that it is necessary to find a way to reach a bigger population of students. This concern likely includes more frequent and clear communications of learning expectations that might seem different than prior student conceptions.

### 5.5 Limitations and Implications

This study presents a few limitations, in part because it used self-report surveys, and the student provided responses on motivation and attitude may not accurately describe their true motivation levels or types. Self-reports rely on what respondents thought or felt about each item,<sup>76</sup> and this form of measurement has an inability to directly observe affective components.<sup>34</sup> Selection bias may also exist,<sup>77</sup> as the participation in either survey was part of a set of assignments where students could choose which specific activities to undertake and obtain full credit for that component of the course without taking a survey. Thus, while there were points associated with completing the surveys, they could be skipped and this dynamic could affect which students participated in the surveys, in unpredictable ways. This study did not evaluate any demographic differences in motivation, as other studies have done.<sup>7,19,49</sup>

The sample number included in this study represented approximately 60% of the whole class population. While the sample population's performance on the ACS final exam was comparable to the whole class, the sample number used in this study may not be representative of the entire general chemistry course population within this institution and/or across other institutions. Lastly, this study did not attempt to define the direction of causality among motivation, attitude, and students' performance on the ACS exam scores. Thus, the correlations

identified here are interesting, and can suggest questions for further that might address causality, but do not currently answer any such questions.

Future studies may be focused on whether students enrolled in certain of majors favor the systems thinking instructional approach more than others. In addition, it may be of interest to assess which types of “bigger picture” appeal to students with differing academic goals. Employing qualitative methods such as interviews or journal entries may be helpful to understand how the systems thinking pedagogy affects students’ motivation and attitudes throughout the semester.

While the findings in this study echoes existing data about students’ motivation in general chemistry courses, it also suggests a few important questions to be considered with a rising trend of systems thinking instructions: What part of systems thinking can promote students’ motivation (ideally intrinsic motivation) to learn chemistry, and how can it create a positive shift in their attitudes toward the subject?

## 5.6 Conclusion

The Situational Motivation Scale (SIMS), a concise instrument developed to assess four different types of motivation, was modified slightly and employed in the chemistry context for the first time. Using the SIMS and ASCIv2, this study sought to evaluate changes in student motivation and attitudes after a semester of general chemistry that included connections of the chemistry content to larger systems. The SIMS was validated by CFA, resulting in retention of 14 items out of the original 16-item scale. This measurement suggested that students in general chemistry tend to be extrinsically motivated, which aligns with previous findings. A systems thinking curricular approach did not provide a move towards more desirable intrinsic motivation

in this study. Multiple regression analysis of the motivation types and performance on an ACS final exam showed that intrinsic student motivation predicts positive effects on the exam score, whereas amotivation was negatively correlated with the exam performance.

Intellectual accessibility and emotional satisfaction domains, as measured with the ASCIv2, also correlate positively with higher scores on an ACS final exam. Lastly, high scores of both cognitive and affective domains were positive predictors of intrinsic motivation.

Because this study was implemented in a course that incorporated systems thinking components, insight into the potential affective impacts of such an approach were also observed. Overall, the results suggested that the systems thinking approaches implemented in this course did not succeed in increasing students' intrinsic motivation. Further examination of the impact of systems thinking on students' cognitive and affective domains are necessary to identify what types of real-life connections are helpful for general chemistry students.

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## CHAPTER 6

### GENERAL CONCLUSIONS

The chapters included in this dissertation explored two aspects of chemistry education: (1) the assessment of general chemistry students' affective states, and (2) the use of technology and context-based instruction to incorporate the role of instruments and applications into the chemistry curriculum. A frequently overlooked aspect of science is what enables the observation of natural phenomena, and the studies presented in this dissertation included the importance of introducing scientific instruments into both laboratory and lecture courses. In addition, how students conceptualized scientific instruments were investigated for the first time.

Chapters 2 and 3 described the uses of augmented reality interface to connect general chemistry students to information about instruments commonly used in educational laboratories. While the tracking data suggested that students did not utilize the application extensively during the target experiment, the use and presence of the application decreased students' anxiety towards instrumentation and increased the perceived intellectual accessibility. These positive shifts in students' attitude are promising, though difficult to attribute exclusively to the AR application, as how students feel is deeply connected to the way they think and behave in learning environments. The usability ratings of the developed application were also satisfactory, indicating that this type of resource could be implemented to help students feel more positively about instrumentation.

Chapter 4 describes a mixed-method study exploring how students conceptualize scientific instruments. The study utilized a new survey and a semi-structured interview to understand students' understanding of how instruments are used in and outside of science. Students' feelings toward learning about instruments were also assessed, revealing that relevancy

and the usefulness of the knowledge are important factors in their motivation to learn. However, many of the interview participants presented a limited understanding of the nature of science, illustrating a potential area of improvement in the general chemistry curriculum.

Chapter 5 summarizes the work investigating students motivation in a first-term general chemistry course, in which a systems thinking based rich context curricular approach was employed. Four types of motivation were assessed at the start and end of the semester, showing that students' intrinsic motivation decreased while extrinsic motivation (specifically, external regulation) and amotivation levels increased. The level of intrinsic motivation was positively correlated with students' final exam scores (ACS exam), whereas extrinsic motivation and amotivation scores were negatively correlated with their exam performance. The results were in line with previously reported motivation studies in chemistry classrooms. These observations demonstrate that not all students may find specific contexts relevant or helpful, and that different contexts must be considered for courses where diverse group of students are enrolled in.

### **Future work**

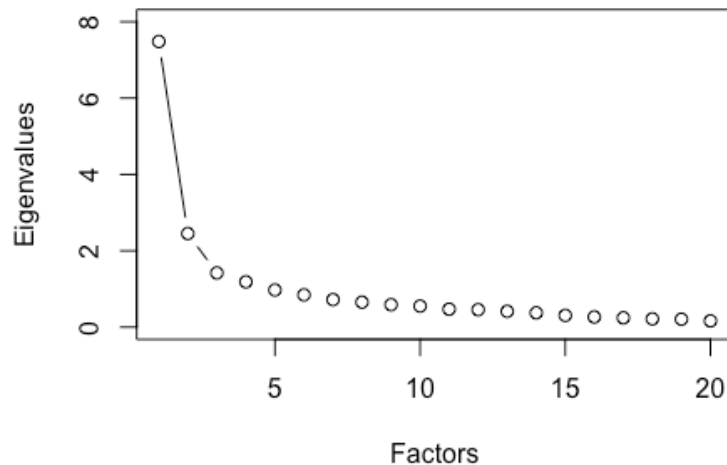
While the augmented reality in educational laboratories (ARiEL) introduced in this dissertation was able to positively change students' attitudes toward instrumentation, inclusion of interactive features may be necessary to enhance its utilization. Considering that the current generation of students are immersed in many interactive technologies, addition of interactive features within the application can potentially enhance students' interest, as well as their perceived practicality of the application. Secondly, based on the interview results from Chapter 4, understanding how upper-level students conceptualize scientific instruments will be of interest. If general chemistry students, most of whom have had limited exposure to scientific instruments, held a narrow view of the role of instruments, studying the upper level students with

more exposure to advanced instrumentation may provide important insight into what factors advance the understanding of the nature of science. Lastly, exploring different scenarios of contexts to incorporate into the systems thinking curricular approach appears to be important, based on the changes in motivation observed in Chapter 5. If relevancy and applicability of knowledge can be leveraged to increase student's interest and understanding of chemical concepts, appropriate contexts that can achieve such objective should be identified.

## APPENDIX A

SUPPLEMENTAL INFORMATION ACCOMPANYING  
CHAPTER 2**Table A1.** SUS Median Score and Total Average Score from the Focus Group Study.<sup>a</sup> Sample size = 12<sup>b</sup> Responses ranged from 1 to 5, where 1 = Strongly Disagree and 5 = Strongly Agree.

	SUS Question	Median <sup>a,b</sup>
1	I think that I would like to use this system frequently.	4
2	I found the system unnecessarily complex.	1
3	I thought the system was easy to use.	5
4	I think that I would need the support of a technical person to be able to use this system.	1
5	I found the various functions in this system were well integrated.	4
6	I thought there was too much inconsistency in this system.	1
7	I would imagine that most people would learn to use this system very quickly.	5
8	I found the system very cumbersome to use.	1
9	I felt very confident using the system.	5
10	I needed to learn a lot of things before I could get going with this system.	1
<b>Average Score (out of 100)</b>		<b>88.75</b>

**Figure A1.** Scree plot of the modified ASCI results.

## APPENDIX B

SUPPLEMENTAL INFORMATION ACCOMPANYING  
CHAPTER 3**Table B1.** Exploratory Factor Analysis (EFA)<sup>a</sup> results for 2-factor, 8-item model. Below results were examined for scale modification.

		Polar Adjectives		Factor 1	Factor 2
Item 1	Easy		Hard	<b>0.499</b>	-0.231
Item 4	Complicated		Simple	<b>0.951</b>	
Item 5	Confusing		Clear	<b>0.772</b>	
Item 10	Challenging	Unchallenging		<b>0.598</b>	-0.135
Item 14	Comfortable	Uncomfortable		-0.324	<b>0.401</b>
Item 18	Safe		Dangerous		<b>0.594</b>
Item 19	Tense		Relaxed	-0.124	<b>0.632</b>
Item 20	Insecure		Secure		<b>0.873</b>

<sup>a</sup>EFA with maximum likelihood (ML) method with oblique rotation.**Table B2.** Side-by-side comparison of the IA and Anxiety subscale scores from the current study and the initial ARiEL study<sup>15</sup> conducted in Spring 2019 semester.

	Current Study <sup>a</sup>		Spring 2019 Report <sup>b</sup>	
	IA	Anxiety	IA	Anxiety
<b>Pre</b>	49.5	42.9	48	43
<b>Post</b>	54.6	37.6	52	37

<sup>a</sup> 2-factor, 6-item model (Model 5, see Table 3.3).<sup>b</sup> Two subscales within the 4-factor, 16-item model; both IA and Anxiety subscales had 4 items.

## APPENDIX C

SUPPLEMENTAL INFORMATION ACCOMPANYING  
CHAPTER 4

**Table C1.** A full version of the tripartite learning outcomes included in the GC-I\* course syllabus.

**Learning Objectives:** Learning objectives for this course are built with three aspects in mind (they are sometimes called tri-partite learning objectives as a result. The idea is that when we consider chemical skills and concepts we need to know (a) what they are; (b) how we know them; and (c) why they matter.

Knowledge: What We Know	Evidential: How We Know It	Relevance: Why It Matters
Benefits and risks of chemicals Explains the concept of “the dose makes the hazard”	Toxicity/exposure Introduce LD50;	At what level is risk acceptable? We have to make decisions about chemicals and their use.
Solve chemical problems with scientific data (graphical or tabulated data)	Graphical and tabulated data come from measurements Measurements have precision and accuracy associated with instruments Error must always be kept in mind	Need to be able to know which chemicals are more dangerous than others; Need to know if ways to measure are adequate to use the chemical knowledge
Describe fundamental components of chemical structure	Mass spectrum shows molecular ion peaks, number of isotopes, and the relative abundances	Differences in isotopes can cause changes in physical and chemical properties of a chemical, thus changing their uses and applications
Explain fundamental features of chemical reactions (balanced equations, stoichiometric problems involving moles, mass, # of molecules, limiting reactant, theoretical yield, and % yield)	The method of continuous variation is an example of a way of knowing stoichiometric ratios	Knowing amounts of reactants can lead to methods to reduce waste – <i>green chemistry</i> . Be prepared for organic chemistry where reaction equations do not include stoichiometry.
Explain chemical reactions in solution (precipitation, acid-base, redox)	Observable to the eye changes (like color change) are not the only ways of identifying and quantifying reactions. Modern titrations include pH or conductivity measurement (or other electrochemical measurements)	We need to know trace contaminant levels in water because it’s important for specific health and environmental consequences. - Nitrates and Lead

Describe the role of chemistry in water resources for human use and the importance of water for sustainability	Instruments (from pH, conductivity, oxygen meters to chromatographic instruments) and analytical techniques allow purification and quality measurement of water	Water quality is directly related to human health and environment
Explain the central role of energy in chemistry and chemical reactions (measurement of energy using calorimetry)	Calorimetry allows the measurement of heat involved in a chemical reaction (heat transferred to or from a substance); Measures of energy transformation efficiency (heat to work) are a key part of using chemistry for energy	Learn specific heat of substances involved in a reaction; can find out how much energy is needed for a heating or cooling process (heating a house, materials used for appliances) Food sciences and dietary energy
Describe atomic structure and its importance in understanding chemistry	Characteristic chemical and physical properties can be observed, measured, and then modeled using a combination of spectroscopy and quantum models Historic experiments such as photoelectric effect	Atoms are building blocks of matter Atomic structure explains different chemical and physical properties of matter
Explain the origin and implication of chemical bonding	Concept of valence can be measured Strengths of interactions of atoms and molecules in materials can be measured	How do different strengths of interaction lead to different properties that can be used? Epoxy vs. glue (bonding vs. intermolecular forces) Diamond vs. graphite
Describe fundamental characteristics of molecules and molecular bonding	Spectroscopic measures that inform our understanding of molecular scale and bulk properties	Water has unique properties that can be understood using ideas related to strengths of interactions.
Explain characteristics of gases and how they are different than condensed forms of matter (liquids and solids)	There are measures that are not dependent on the identity of the gas and others that are dependent on the identity. Measures of bulk vs. molecular properties (e.g. measuring pressure/temperature vs. spectroscopic properties)	Understanding the behavior of the Earth's atmosphere depends on both common gas behaviors (ideal gases as a model) and unique gas behaviors (what makes something a greenhouse gas).
Explain the concept of intermolecular forces	Measurements of viscosity, surface tension, phase changes	Chemical basis of life such as how cells are organized is closely tied to the nature of intermolecular forces



**Table C2.** List of survey questions.

<b>Free-Response</b>
How would you define 'scientific instruments' in your own words?
<b>Likert-Items</b>
1. Scientific instruments contribute to things I do in my everyday life.
2. Instruments is helpful in getting out of lab quicker.
3. I find learning about instruments used in lab to be interesting.
4. I check my data from instruments to make sure they are sensible.
<sup>a</sup> 5. My everyday life would be the same without scientific instruments.
6. Instruments allow me to record observations of nature (natural phenomena).
7. I feel confident I can safely use instruments in laboratories.
8. Readouts (results) from instruments in lab are trustworthy.
9. Outside of science laboratories, scientific instruments have many uses.
10. I think about the role of instrument(s) I use in each experiment.
11. Using scientific instruments makes experiments more interesting.
12. Laboratory instruments provide accurate results.
<sup>a</sup> 13. The world we live in would have advanced similarly without instruments.
14. Instruments help with solving problems in the world.
15. I am interested in knowing how instruments operate.
16. User error is common with instruments and can lead to inaccurate results.

<sup>a</sup> Responses were reversed before analysis.

**Table C3.** List of interview questions.

Questions	
1	How would you define “scientific instrument”?
2	What are some examples of instruments? Why would they be classified as instruments?
3	What do you believe the general purpose of scientific instruments is?
4	How do you think instruments are used in your personal life?
5	What are some examples of using instruments in life?
6	What are some examples of using instruments in lab?
7	How closely do you think instruments are related to you?
8	Choose an instrument; How would your life be different without the instrument of choice?
9	How are instruments used in science?
10	What are some things that would not be possible without instruments?
11	What are some things that would still be possible without instruments?
12	When do you think instruments are most useful?
13	Do you think instruments contributed to advancement of science? Why or why not?
14	How do you feel toward learning about instruments?
15	Imagine you are standing in your science laboratory. How would you describe your feelings when you think about using new instruments in chemistry labs?
16	How do you think your attitudes are different when you encounter a new piece of technology (i.e., new phone or computer) versus when you are introduced to a new instrument in laboratory?
17	Beyond laboratory, how motivated are you to use/learn about instruments?
18	How important is learning about instruments to you?
19	What do you think motivates you the most to learn about instruments in lab?
20	When you make a measurement during an experiment using an experiment, how do you decide whether or not the data you obtained are trustworthy?
21	Why or why not do you think it is necessary to evaluate the quality of your data obtained using instruments in chemistry laboratory?
22	You have just observed a soufflé rise as it bakes. How does this differ from the observation you would make in chemistry laboratory working with lab instruments?
23	How is encountering chemistry in everyday life different from performing experiments in chemistry laboratory?
24	Do you feel that your learning about instrumentation is sufficient in chemistry laboratory? Why or why not?
25	What else do you think can be done to help you and other students be more familiar with instruments, whether it is in laboratory or lecture?
26	Has your definition of scientific instruments changed at all? If so, how?

**Table C4.** A complete codebook of the free response question.

Category	Basic (B)		Intermediate (I)		Advanced (A)	
<b>Classification (C)</b>	Stuff, item, object, anything, something (vague terminology) “Instrument” unelaborated (CB)		“Instrument” elaborated (C-In)	Tool, machine, technology, equipment, device (CI)	-	
<b>Uses (U)</b>	In/during experiment/laboratory /chemistry/scientific experiments (UB)	By scientists (UB-S)	In science, research, scientific research (Broader than just ‘experiments’ or ‘chemistry’ they would be familiar with) (UI)		In life, natural settings, natural world (UA)	
<b>Purpose (P)</b>	For scientific purposes/experiments, to conduct research, to perform experiments  Of science (PB)		Data collection: Measure/collect/record /gather/reading/calculate data, observation, measurements (PI-D)	Accurate/Precise data collection (PI-D-A/P)	Beyond data collection: simplify/make easier/enable/ increase efficiency of experiments, enhance observations  (But not simply “things” or “something”) (PA)	Test Hypothesis, prove theory, answer/solve scientific problems/questions, learn/explore/ understand science (PA-T)
	Implicit & vague purpose (i.e., help ‘figure things out’, ‘accomplish/explain something’, ‘measure something’, ‘get information’) (PB-I)			Quantitative (PI-D-Qn)		Measure/explain natural phenomenon (PA-N)
Qualitative (PI-D-Ql)				Advance the world/science (PA-L)		
		Both (PI-D-QQ)		Discover (PA-D)		
		Help/assist experiments/research (no additional explanation/elaboration as to how they help) (PI-A)		See/do things otherwise can't, do what humans can't do (PA-S)		

**Table C5.** A complete codebook for the interview study, where (I) includes list of affective, cognitive, and psychomotor codes, (II) includes purpose and example codes, and (III) includes all subcodes used for the analysis.

(I)	Affective (A)		Cognitive (C)		Psychomotor (Pm)
1	Want to do it right/correctly → Student expresses they want to do things right in lab (experiments correctly, etc.)	1	Understand/recognize the immediate relatedness/impact/contribution/difficulty/importance → Makes some connections to outside 'lab' space, realizes immediate application or impact of instruments outside of science; recognizes some roles instruments have had in science	1	Evaluate data - Yes → Student evaluates data in lab
2	Want to know/understand → Student mentions that they want to know/understand concepts, experiments, etc.	2	Understand/recognize the wide relatedness/impact/difficulty/importance → Aware of the wide application and impact of instruments in life, recognizes the deep connections they have to our life, science, and society; recognizes the interconnected roles instruments have had in science	2	Evaluate data - Sometimes → Student evaluates data sometimes
3	Negative feelings/attitude → Student expresses negative feeling(s) such as anxious, nervous, pressured, stressed, etc.	3	Yes - different, important, enough learning, definition changed → Thinks instruments contributed to science; Data evaluation is important; they feel learning is sufficient in lab; their definition has changed after the interview	3	Ask TA → Ask TA for help (e.g., when learning new instruments)
4	Positive feelings/attitude → Student expressed positive feeling(s) such as interested, happy, etc.	4	No - not different, not important, not enough learning, definition didn't change → Doesn't think instruments contributed to science; Data evaluation is important; they feel learning is sufficient in lab; their definition has changed after the interview	4	Ask/watch other students → Ask other students or watch other groups in lab
5	Attitude different → Student expresses their attitude is different towards instruments vs. technology	5	Useful, beneficial → Think learning about instruments is useful	5	Try/think on my own → Try to find out how to use it on their own; evaluate data on their own
6	Attitude not different → Student expresses their attitude is different towards instruments vs. technology	6	Misconception → Any form of misconception (e.g., graduated cylinder is used to measure accurately)	6	Compare to expectations → Evaluate data based on expectations
7	Motivated → Motivated to learn				
8	Not very motivated → Not motivated to learn				

(II)	<b>Purpose (P)</b> Any responses referring to the purpose of instruments/how they are used (e.g., 'they are used for measurement')		<b>Instrument Examples (IEX)</b> Code used to classify specific "instruments" students mention, such as 'thermometer'		<b>Examples (EX)</b> Code used to classify examples of instrument usage (e.g., 'thermometer is used to measure outside temperature or body temperature')
1	For measurement/data/quantitative data	1	Measurement tools (e.g., scale, graduated cylinder, ruler, thermometer, pipette, timer)	1	General (e.g., measuring with ruler or measuring cup)
2	Qualitative	2	Glassware (e.g., beaker, flask, test tubes)	2	Other (e.g., examples with cars)
3	To help with experiments/provide vessel	3	Others - lab related (e.g., calorimeter, spectrometer, hot plate)	3	
4	Beyond data collection (anything besides 1, 2, and 3)	4	Others - not chem lab related (e.g., clock, computer, oven, calculator)	4	

(III)	<b>Subcodes</b> Can be used in addition to C, A, Pm, EX or P codes, mostly as a reasoning for actions/feelings/thoughts
A	For career/future reasons (e.g., motivated because of future career; 'might need it in the future')
B	For course/academic related reasons (e.g., motivated because of grade)
C	Due to time constraint (e.g., don't evaluate data because of lack of time)
D	Depends on level of understanding/background knowledge (e.g., 'thinking about chemistry outside of lab would depend on background knowledge')
E	Making errors/instrument misuse/chemicals (e.g., nervous because...; check data because you can make errors)
F	To learn what I'm supposed to (e.g., evaluate data so I can learn what I need to)
G	Depends on relevance (e.g., I find it more interesting if I'm going to use it more)
H	Accuracy/Precision-related (e.g., 'without instruments won't know accurate measurements')
I	Uncertainty-related (e.g., 'it would just be a lot of guessing')
J	Uniformity-related (e.g., 'there won't be a standard way to measure...')
K	Goal/Purpose-related (e.g., 'it's different because in labs, you have specific goals...')
L	Detail-related (e.g., 'make more observations and write them down in lab')
M	Don't know what I'm doing (e.g., nervous because I don't know what I'm doing)
N	If I know how to do it (e.g., interesting once I know how to do it)
O	Mentioned GC-I* online activity (Lavoisier & Priestley)
P	More than I realize (acknowledge there are more applications and uses of instruments after the interview)
Q	Don't think about it (e.g., 'it's different, because in life you don't think about chemistry')
R	Obligated to learn (e.g., 'I feel like I have to, because I'm in lab')

## APPENDIX D

SUPPLEMENTAL INFORMATION ACCOMPANYING  
CHAPTER 5

(1) The modified Situational Motivation Scale (SIMS) for general chemistry after confirmatory factor analysis.

**Table D1.** List of the SIMS items used in this study.

<b>Directions:</b> There are 16 statements below. Read each statement carefully. Please choose the response for each statement that best describes how much the statement reflects the reason you are currently engaged in this class (CHEM 177).		
<b>Type of Motivation</b>	<b>Item #</b>	<b>Item</b>
Intrinsic	1	Because I think this class (CHEM 177) is interesting
	5	Because I think that this class (CHEM 177) is pleasant
	9	Because this class (CHEM 177) is fun
	13	Because I feel good when taking this class (CHEM 177)
Identified Regulation	2	Because I am taking it for my own good
	6	Because I think that this class (CHEM 177) is good for me
	10*	By personal decision
	14	Because I believe that this class (CHEM 177) is important for me
External Regulation	3	Because I am supposed to take it
	7	Because it is something that I have to do
	11*	Because I don't have any choice
	15	Because I feel that I have to do it
Amotivation	4	There may be good reasons to take this class (CHEM 177), but personally I don't see any
	8	I'm taking this class (CHEM 177) but I am not sure if it is worth it
	12	I don't know; I don't see what this class (CHEM 177) brings me
	16	I'm taking this class (CHEM 177), but I am not sure it is a good thing to pursue it

\*Items were removed during post-hoc modification process based on the CFA results.

## APPENDIX E

## INSTITUTIONAL REVIEW BOARD APPROVAL FORM

**IOWA STATE UNIVERSITY**  
OF SCIENCE AND TECHNOLOGY

Institutional Review Board  
Office for Responsible Research  
Vice President for Research  
2420 Lincoln Way, Suite 202  
Ames, Iowa 50014  
515 294-4566

**Date:** 10/08/2019

**To:** Thomas Holme

**From:** Office for Responsible Research

**Title:** **Developing Augmented Reality Applications for Chemistry Laboratory**

**IRB ID:** 17-300

**Submission Type:** Modification

**Exemption Date:** 10/03/2019

The project referenced above has been declared exempt from most requirements of the human subject protections regulations as described in 45 CFR 46.104 or 21 CFR 56.104 because it meets the following federal requirements for exemption:

2018 - 2 (ii): Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) when any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation.

2018 - 3 (i.B): Research involving benign behavioral interventions in conjunction with the collection of information from an adult subject through verbal or written responses or audiovisual recording when the subject prospectively agrees to the intervention and information collection and any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation. - 3 (ii) If research involves deception, it is prospectively authorized by the subject.

The determination of exemption means that:

- **You do not need to submit an application for continuing review. Instead, you will receive a request for a brief status update every three years. The status update is intended to verify that the study is still ongoing.**
- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any *modifications to the research procedures* (e.g., method of data collection, nature or scope of information to be collected, nature or duration of behavioral interventions, use of deception, etc.), any change in *privacy or confidentiality protections*, modifications that result in the

*inclusion of participants from vulnerable populations, removing plans for informing participants about the study, any change that may increase the risk or discomfort to participants, and/or any change such that the revised procedures do not fall into one or more of the [regulatory exemption categories](#). The purpose of review is to determine if the project still meets the federal criteria for exemption.*

- All **changes to key personnel** must receive prior approval.
- **Promptly inform the IRB of any addition of or change in federal funding for this study.** Approval of the protocol referenced above applies only to funding sources that are specifically identified in the corresponding IRB application.

**Detailed information about requirements for submitting modifications for exempt research can be found on our [website](#).** For modifications that require prior approval, an amendment to the most recent IRB application must be submitted in IRBManager. A determination of exemption or approval from the IRB must be granted before implementing the proposed changes.

Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

Additionally:

- All research involving human participants must be submitted for IRB review. **Only the IRB or its designees may make the determination of exemption**, even if you conduct a study in the future that is exactly like this study.
- **Please inform the IRB if the Principal Investigator and/or Supervising Investigator end their role or involvement with the project** with sufficient time to allow an alternate PI/Supervising Investigator to assume oversight responsibility. Projects must have an [eligible PI](#) to remain open.
- **Immediately inform the IRB of (1) all serious and/or unexpected [adverse experiences](#) involving risks to subjects or others; and (2) any other [unanticipated problems](#) involving risks to subjects or others.**
- **Approval from other entities may also be needed.** For example, access to data from private records (e.g., student, medical, or employment records, etc.) that are protected by FERPA, HIPAA or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted.**
- Your research study may be subject to [post-approval monitoring](#) by Iowa State University's Office for **Responsible Research**. In some cases, it may also be subject to formal audit or inspection by federal agencies and study sponsors.
- Upon completion of the project, transfer of IRB oversight to another IRB, or departure of the PI and/or Supervising Investigator, please initiate a Project Closure in IRBManager to officially close the project. For information on instances when a study may be closed, please refer to the [IRB Study Closure Policy](#).

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or [IRB@iastate.edu](mailto:IRB@iastate.edu).