GRADUATE TEACHING ASSISTANT FIDELITY OF IMPLEMENTATION IN INTRODUCTORY CHEMISTRY AND PHYSICS LABORATORIES: IMPACT ON SCIENCE PRACTICE PROFICIENCY

by

Annalisa Smith-Joyner

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Director of Thesis: Dr. Joi P. Walker

Major Department: Chemistry

This study reports the fidelity of implementation of the Argument-Driven Inquiry (ADI) instructional model by graduate teaching assistants (GTAs) in introductory chemistry and introductory physics laboratories at East Carolina University (ECU). The ADI instructional model had been fully implemented in the General Chemistry I & II laboratories for several semesters, whereas General Physics I & II laboratories were observed during the first semester of course-wide implementation. An ADI-specific observation protocol was developed and used to document the facilitation techniques of two GTAs in each course for three investigations during Fall 2018 and Spring 2019. The ADI-specific observation protocol was used to determine if *student-centered* facilitation techniques, by guiding students through the process, or *instructor-centered* facilitation techniques (lecturing at the students and providing direct answers to questions) were used by the GTA. The ADI-specific observation protocol revealed that one of the GTAs in General Physics I provided primarily *student-centered* facilitation techniques while the other GTA provided primarily *instructor-centered* facilitation techniques during some of the stages of the ADI instructional model throughout the semester. The students' results on a practice-focused end-of-course laboratory

practical exam were used to determine proficiency with science practices. There was not a significant difference in the mean scores on the end-of-course practice-focused laboratory practical exam in the General Chemistry I & II and General Physics II sections. These results indicate that for these three courses the facilitation techniques of the GTAs had minimal impact on the students' development of science practices. There was a significant difference in the mean scores by the students in General Physics I laboratories, which suggests that differences in facilitation techniques for this section impacted student proficiency with science practices.

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By

Annalisa Smith-Joyner

APPROVED BY:

DIRECTOR OF THESIS: ______________________________
Joi P Walker, PhD

COMMITTEE MEMBER: ______________________________
Adam R. Offenbacher, PhD

COMMITTEE MEMBER: ______________________________
Brian E. Love, PhD

COMMITTEE MEMBER: ______________________________
Mark W. Sprague, PhD

DEPARTMENT CHAIRPERSON: ______________________________
Andrew T. Morehead Jr., PhD

DEAN OF THE GRADUATE SCHOOL: ______________________________
Paul J. Gemperline, PhD

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# Chapter 1. Introduction

## Laboratory Background

Historically laboratory instruction was introduced into the chemistry curriculum to reinforce the content from lecture and to prepare students at the university level to become industrial bench chemists and workers in research laboratories (Reid & Shah, 2007). For this reason, the experiments in a traditional laboratory setting instructed students in technique and procedure with less focus on science inquiry. This has led to students going through the motions of the experiments without having a deep connection with the subject matter or understanding the role of scientific inquiry (Reid & Shah, 2007). Now, the industrial chemist positions are not in high demand (Reid & Shah, 2007) and the majority of students are now taking these introductory courses as prerequisites for professional programs. An issue with the traditional laboratory curriculum is that students are not taught how to approach experiments scientifically (NRC, 2012). This has prompted a need for the laboratory portion of disciplinary science courses to evolve in order to engage students in authentic science practices.

Science practices that might be introduced in the laboratory curriculum include asking questions, developing and using models, designing and performing investigations, analyzing and interpreting data, problem solving, engaging in argumentation from evidence, and effectively communicating information (Bruck & Towns, 2013; NRC, 2012; NGSS Lead States, 2013). How students perform science practices in a classroom can be examined as described by Ford (2008). Scientists explore the natural world with *empirical* science practices by planning and carrying out an investigation, followed by analyzing and interpreting data (Ford, 2008). Scientists describe the natural world to peers and the community with *representational* science practices (Ford, 2008), such as constructing an explanation, arguing from evidence, sharing findings, and evaluation and critique.

**Argument-Driven Inquiry**

The Argument-Driven Inquiry (ADI) instructional model (Walker et al., 2012) was the foundation for reform of the introductory laboratories for chemistry, biology, and physics at East Carolina University (ECU). These reformed laboratories were designed to use similar language across the introductory courses in all three disciplines that would introduce and reinforce important science practices, thus, allowing for smoother transitions into upper-division laboratory courses or into undergraduate research. As seen in Table 1, the traditional laboratory model exposes students to the empirical science practices by having them perform experiments with known outcomes; however, the traditional instructional method does less to expose students to the representational science practices (Walker et al., 2016).

Table 1
*Science practice participation opportunities – Traditional vs ADI*

| Science Practice | Traditional | ADI |
|---|---|---|
| **Empirical** | | |
| Plan Investigation | No | Yes |
| Perform Investigation | Yes | Yes |
| Analyze/Interpret Data | Yes | Yes |
| **Representational** | | |
| Form an Explanation | Yes | Yes |
| Argue from Evidence | No | Yes |
| Share with Peers | No | Yes |
| Evaluate & Critique Ideas | No | Yes |

In the ADI instructional model, students are guided through seven empirical and representational science practices (Table 1) in each investigation through collaboration in small groups. The ADI instructional model engages students in authentic science practices through eight stages:

1. The scientific concept is identified with a guiding question.
2. Working in small groups, the students design an investigation in order to collect the data they need to answer the guiding question.
3. The groups analyze the data and develop an initial argument.
4. The students participate in an argumentation session where they share their argument and critique other groups' arguments.
5. The students return to their group and discuss the information that was obtained in the argumentation session.
6. The students communicate their findings in an individual laboratory report.
7. The students engage in a double-blind peer review.
8. The students make necessary edits and submit their report for grading.

There is substantial amount of research that indicates the ADI instructional model addresses the missing science practices of traditional laboratory courses. There was significant improvement with data analysis and the construction of an argument for students in ADI sections when compared to traditional laboratories at a community college (Walker et al., 2012). Research has also indicated that female students' attitudes towards science significantly increases and there is no loss in positive attitude towards science in males when comparing the ADI model to traditional laboratory (Walker et al., 2011). Additional research has shown that students in ADI sections outperformed students in a traditional setting on an end-of-course practical exam that required the students to design an investigation, collect and interpret data, and form an argument. In the United States, for Science, Technology, Engineering, and Mathematics (STEM) fields African Americans, Native Americans, Alaskan Natives, Hispanic, and multiracial students are considered underrepresented minorities (URMs) (National Science Foundation, 2015). The achievement gap for URM students was closed with the ADI instructional model (Walker et al., 2016). Improvement of written laboratory reports and the strengthening of argumentation skills in a semester has been observed for students in ADI laboratories (Walker & Sampson, 2013).

**GTA Effect**

Introductory laboratories at many universities in the United States are often facilitated by graduate teaching assistants (GTAs) with the assistance of undergraduate teaching assistants (UTAs) (Wheeler et al., 2017). GTAs do not typically attend graduate school in chemistry in order to teach (Wheeler et al., 2019) but are typically assigned to teach as soon as they become graduate students (Burke et al., 2005). Often it is assumed that GTAs know how to teach, how the laboratory should be structured, and that they are comfortable with an authoritative role in the level of chemistry they are about to teach (Burke et al., 2005). Previous research suggests that due to research being a primary task for many GTAs and teaching being a secondary task, there is little focus on the development of effective teaching methods (Addy & Blanchard, 2010). In an *instructor-centered* classroom, the students are provided information in a lecture style and/or are provided answers to their questions, whereas in a *student-centered* classroom, students explore scientific phenomena and are asked guiding questions that assist to build on their pre-existing knowledge. Since GTAs are typically unfamiliar with effective ways to instruct science in a guided-inquiry format, they tend to rely on *instructor-centered* techniques (Addy & Blanchard, 2010; Wheeler et al., 2017, 2019).

Burke et al. (2005) suggest that GTAs go through an authentic training intervention that implements the mentorship of experienced GTAs in order to break the teacher-as-information-source mentality that is the model for most GTAs. The training should occur throughout the semester and should reflect some of the challenges and discoveries their students will go through (Burke et al., 2005). If measurable goals are in place it would be possible to determine if the GTAs are facilitating their sections effectively and it would be possible to adjust the training as needed if it is being done weekly (Sawada et al., 2002). These goals can be either measured with self-reports or observation protocols. A self-report is an individual's description of their beliefs or behaviors usually reported through an interview or a survey, whereas an observation protocol is used by a secondary party to document observable techniques.

**Observation Protocol**

Observation protocols are more impartial than self-reports in measuring the behaviors of GTAs (Velasco et al., 2016). The three structured styles of observation protocols are holistic, segmented and continuous. Holistic observation protocols such as the Reformed Teaching Observation Protocol (RTOP) look at the whole classroom setting for a predetermined set of items that occur (Sawada et al., 2002). When a researcher uses a segmented observation protocol, such as Laboratory Observation Protocol for Undergraduate STEM (LOPUS), behaviors that occur during a specified time frame (e.g. 2 min) are documented (Velasco et al., 2016). Continuous protocols, like Real-time

Instructor Observation Tool (RIOT), collect information about behaviors that occur throughout the whole laboratory (Wilcox et al., 2015).

RTOP was developed by Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) when classroom observation tools were just beginning to align with classroom reform (Sawada et al., 2002). ACEPT wanted to develop an instrument that considered inquiry-based, *student-centered* teaching methods that was also standard based (Sawada et al., 2002). There was a need for a protocol that showed evidence of validity and reliability that focused on reform in mathematics and science and was easy to administer throughout K-20 (Sawada et al., 2002). The researchers developed 25 items in three main categories (lesson design and implementation, content, and classroom culture) that should be present in a reformed classroom. Both content (propositional knowledge and procedural knowledge), and classroom culture (sub-divided into communicative interactions and student/teacher relationships) were further divided into two categories, resulting in 5 items for each section (Sawada et al., 2002).

LOPUS was an adaptation of Classroom Observation Protocol for Undergraduate STEM (COPUS) that removed classroom specific questions (e.g. clicker questions) and added laboratory specific questions (Velasco et al., 2016). The developers of LOPUS wanted to show that laboratory instruction is based on interaction, so this protocol looks at both the initiator and the nature of student-TA verbal interaction in a traditional style laboratory (Velasco et al., 2016). LOPUS was used to code behaviors from a video-taped laboratory session as either TA instructional behaviors or student behaviors; any verbal interactions would have a secondary code attached to it that indicated who initiated it and the nature of the interaction (Velasco et al., 2016).

RIOT uses an applet to record TA behavior in real-time in order to determine the percentage of time that is spent on each of the ten activities (Wilcox et al., 2015). These activities are divided into four major categories: talking at students, shared student/TA dialogue, observation, and not interacting (Wilcox et al., 2016). The data from the RIOT observation is then used to determine the TA's teaching profile (Wilcox et al., 2015). Since RIOT is performed during real-time it is possible to use the results to tailor weekly TA training sessions (Wilcox et al., 2015).

There are advantages and disadvantages of each observation protocol type. Holistic and segmented protocols would work best when using video recorded laboratory session. With these protocols, the researcher is able to score multiple behaviors that occur at the same time in the laboratory, whereas with a continuous protocol this would be very difficult. A disadvantage with segmented protocols is that they focus on predetermined criteria without focusing on student-instructor interaction and therefore do not indicate that the laboratory learning experience is based on interaction. The major issue when using holistic protocols is that the laboratory session has to be recorded, watched multiple times, and then analyzed. Therefore, it is the most time-consuming observation protocol. A continuous protocol would be the best instrument to use when the researcher wants an in-depth look at one particular aspect of instruction as it occurs (Wilcox et al., 2015).

**Purpose**

This mixed method study addressed how graduate teaching assistants (GTAs) implementation of the ADI instructional model impacted student science practice proficiency. A convergent mixed methods design was used, in which qualitative and quantitative data were collected in parallel, analyzed separately, and then merged. In this study, the students' first investigation laboratory report was used to determine the equivalency of the students in each disciplinary section at the beginning of the semester. The student practice-focused end-of-course laboratory practical exam (practical exam) results were used to assess student proficiency with science practices. An observation protocol developed for ADI was used to determine the *fidelity of implementation*, i.e. are the desired techniques for the method being implemented by the GTAs? For the ADI instructional model, *student-centered* facilitation techniques are preferred over *instructor-centered* facilitation techniques.

The reason both quantitative and qualitative data was collected was to measure impact of implementation styles of the GTAs on students' proficiency with science practices. Two research questions guided this study:

Research Question 1: Does graduate teaching assistant implementation of Argument-Driven Inquiry impact student performance on a practice-focused end-of-course laboratory practical exam in introductory chemistry?

Research Question 2: Does graduate teaching assistant implementation of Argument-Driven Inquiry impact student performance on a practice-focused end-of-course lab practical in introductory physics?

# Chapter 2. Methods

All work was conducted in introductory chemistry and introductory physics laboratories at ECU, a Primarily Undergraduate Institution (PUI) in the southeastern portion of the United States, during the Fall 2018 and Spring 2019 semesters. Nearly 30,000 students are enrolled at the PUI annually with about 80 percent of those students being undergraduate students. Students enrolled in the general chemistry and general physics laboratory sections have diverse majors (i. e., disciplinary science, engineering, pre-health) and take these courses to satisfy a portion of their natural science general education credit.

## Course Descriptions

Students take a general chemistry lecture course concurrently with the laboratory course. The general chemistry laboratory sections meet once a week for three hours. There are approximately forty-eight students in each laboratory section that is facilitated by a professor or senior GTA assisted by either a second GTA or an UTA. Occasionally the general chemistry laboratory sections have an UTA that observes how the laboratory is facilitated while they take a course that instructs them how to be an effective UTA. In chemistry, investigations took place over a four-week cycle that guided the students through the aspects of the ADI instructional model. During the first week, the students were introduced to the science concept and techniques by participating in a pre-laboratory activity. For example, during the physical properties investigation for General Chemistry I (GC1) the students learn about accuracy and precision by measuring and weighing 10 mL of water using a beaker, graduated cylinder, and volumetric pipette to determine the density of water. The students then used the concept and techniques to develop a proposal for an inquiry-investigation that they conducted the second week. For example, during the proposal stage of the physical properties investigation, students discussed what methods would be used to determine the extensive properties of mass and volume in order to calculate the intensive property, density (Table 2). After the inquiry-investigation was completed, the students developed a tentative argument using a whiteboard. The whiteboard allows the students to present their answer to the guiding question, data, and their justification of why their evidence led them to the claim they made (Figure 1). Using a whiteboard allows the students to make changes to either their justification or their claim after they complete an argumentation session. The students then wrote individual laboratory reports outside of class that went through a double-blind peer-review the third week of the laboratory. Finally, the students make any necessary edits to their laboratory reports and submit them individually to be graded.

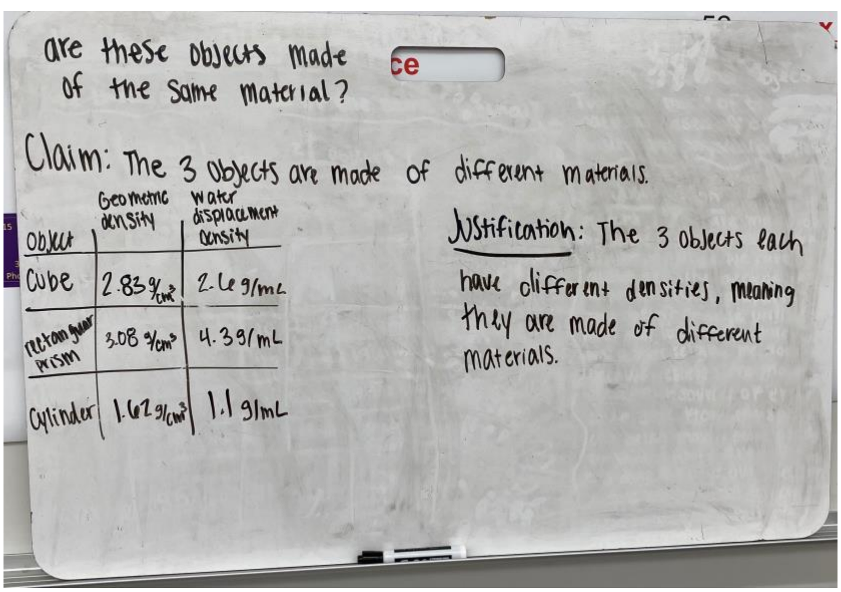


*Figure 1.* Sample student whiteboard for the density investigation in GC1

Table 2
*Description ADI content observed within each disciplinary laboratory*

| Course | Science Concept | Guiding Question | Description |
|---|---|---|---|
| General Chemistry I | Physical Properties | Are these objects made of the same material? | Determine if three unknown objects are made of the same material. |
| | Chemical Reactions | What are the products of a chemical reaction? | Using percent yield, determine which chemical reaction occurred. |
| | Solutions & Molarity | What is the composition of pirate purple dye? | Determine how many grams of red and blue dye are needed to produce Pirate Purple. |
| General Chemistry II | Intermolecular Forces | Why do liquids evaporate at different rates? | Relate evaporation rates to intermolecular forces. |
| | Kinetics | How fast does crystal violet decolorize? | Determine the rate law for crystal violet in decolorization with NaOH. |
| | Buffers & Acid-base Titrations | What is the buffer region of an acid-base titration? | Determine the chemical species present in each portion of a pH titration curve. |
| General Physics I | Reaction Time | Do two people have the same reaction time? | Using a normal curve, determine if people have the same reaction time. |
| | Motion in 1-dimension | Does the force that the fan exerts depend on the mass of the cart? | Using masses and a fan, determine if force is constant. |
| | Harmonic Motion | When does the spring's mass matter? | Determine the amount of mass needed to make the spring's mass negligible. |
| General Physics II | Resistance | Does a light bulb behave like a resistor? | Build a circuit to determine if a lamp is similar to a resistor. |
| | Diffraction | Are hairs from different people the same diameter? | Using Babinet's principle, determine the thickness of hair with a laser. |
| | Nuclear Decay | What is the decay constant of this metal? | Determine the decay constant of copper. |

The general physics laboratory students are typically enrolled in either algebra-based or calculus-based lecture courses simultaneously with the laboratory course. There are approximately twenty-two students in each laboratory section that is facilitated by one GTA. Since the general physics laboratories only last for two hours, some adaptation to the ADI instructional model was required. Students performed the pre-lab during the first week, followed by proposal development and the investigation in the second week. The students then participated in an argumentation session the third week, and the peer-review was completed online with Peergrade individually (*Peergrade*, n.d.). The students in each section were provided videos recorded by an instructor on writing the laboratory report and performing a peer-review. Once the physics laboratory reports have undergone peer-review, the students make any necessary edits and then submit their laboratory reports for grading by the GTA.

**GTA Training**

All of the GTAs observed had equivalent preparation to facilitate the ADI instructional model and had met the same requirements for the laboratory course that they facilitated. The GTAs were selected from individuals that participated in a summer training on the facilitation of the ADI instructional method. The summer training consisted of a one-day training with GTAs from chemistry, physics, biology and geology and a ½ -day in-department training in their specific discipline, followed by weekly meetings during the semester.

During the combined training, the GTAs were split into groups of 3-4 that consisted of GTAs from at least two other disciplines. The GTAs were guided through activities that showed the difference between active and passive learning and techniques for facilitating groups. The GTAs also learned why the laboratories were being standardized across disciplines and how the ADI instructional model would prepare students for upper-division laboratory courses and research in faculty laboratories. The GTAs from all disciplines performed the density investigation from chemistry, participated in an argumentation session, and conducted a peer review. This training was structured to introduce GTAs to the ADI instructional model to desired techniques for facilitation. GTA roles in a traditional laboratory typically align with *instructor-centered* facilitation techniques, however, in the ADI instructional model the GTAs are expected to provide *student-centered* facilitation techniques (Walker et al., 2016).

**Participants**

GTAs facilitating two sections of General Chemistry I (GC1) & General Chemistry II (GC2) and General Physics I (GP1) & General Physics II (GP2) were the participants in this study. Institutional review board (IRB) approval was obtained for the study (Appendix A), and the GTAs voluntarily consented (Appendix B) to participate in the research and pseudonyms were used throughout the study. For each course, an experienced GTA, represented with an 'E' name (e.g. Estlin) and a novice GTA, represented with a 'N' name (e.g. Nelly), were observed (Table 3). A novice GTA was defined as a GTA that had no experience facilitating the ADI instructional model as a GTA prior to this project. The experienced GTAs had at least one semester of facilitation as a GTA in order to be considered for this study.

Nelly and Emry had attended the teaching laboratory course for UTAs during their undergraduate program and worked as UTAs. Emry had previously aided in the facilitation of two semesters as an UTA at ECU and had facilitated four semesters (one semester traditional, three semesters ADI) as a GTA prior to being observed. Evren had taught an active classroom with laboratory style prior to this study for six semesters that required instructors to lecture for ten minutes and then students worked in groups of 2-3 on an activity or problem for ten minutes. Each GTA in the chemistry department typically facilitates two sections of laboratory and each GTA in the physics department typically facilitates three sections of laboratory. The GTA in each section was observed by a researcher that used the ADI-specific observation protocol (Appendix C).

Table 3
*Experience by GTAs in GC1 & GC2 and GP1 & GP2 laboratories*

| **GTA** | **Course** | **Traditional (semesters)** | **ADI (semesters)** | **UTA* (semesters)** |
|---|---|---|---|---|
| Nelly | GC1 | 1 (organic) | 0 | 3 |
| | GC2 | | 1 (GC1) | |
| Emry | GC1 | 1 | 3 | 2 |
| | GC2 | | 4 | |
| Noon | GP1 | 10 | 0 | 0 |
| Estlin | GP1 | 2 | 1** | 0 |
| | GP2 | | 2 (GP1) | |
| Evren | GP2 | 8 | 1 | 0 |

*ADI format, **Estlin assisted facilitation of the pilot section during Summer 2018

**ADI-Specific Observation Protocol**

Instructors in GC1 and GC2 laboratories were observed for the 3-week investigation in order to design a continuous observation protocol that would consider each stage of a complete ADI investigation. The goal of this continuous observation protocol was to record facilitation techniques demonstrated by the GTA as they interacted with the students throughout an entire laboratory period during the 3-week investigation. The observation protocol went through several iterations in order to represent what had been witnessed in the laboratory. The observation protocol consists of concise, objective descriptions with a gradient aspect from *student-centered* facilitation techniques (e.g. instructor allows students to independently analyze data) to *instructor-centered* facilitation techniques (e.g. instructor leads description of proper data analysis and calculations in stepwise fashion) for the researcher to document the observed behaviors (Appendix C, Tables 16 & 17). The observation protocol has at least one option for *student-centered*, *marginal* (e.g. instructor gives some aid and offers suggestions in data analysis), and *instructor-centered* facilitation techniques for each section of the ADI instructional model (e.g. developing a proposal). The observer checks the appropriate box once a facilitation technique is observed. The observation protocol also has a place to document the amount of time allowed for the argumentation session and the post-argumentation discussion (Appendix C, Table 17).

During the summer of 2018, the ADI-specific observation protocol was used to observe four instructors facilitating general chemistry sections in order to provide validity evidence for the observation protocol and to determine if the instrument's design revealed *fidelity of implementation*. The observation protocol was then used by different research team members to observe GTAs in general biology, general chemistry, general physics laboratories while they facilitated their sections. These members compared the results from their observations to determine if the instrument was capturing the events occurring across disciplines. The instrument found similar results for each portion of ADI between the disciplines during each of the stages of the ADI instructional model. For this reason, the research team determined that there was sufficient evidence of content validity and reliability that the instrument could be used for data collection.

The observation protocol was used to observe the first investigation, an investigation in the middle of the semester, and the last investigation for each section. During one three-week investigation, two members of the research team observed the GTA in order to establish inter-rater reliability. Any differences between the two observers were resolved with discussion.

### Laboratory Reports

The laboratory reports that students write for the ADI instructional model are 2-pages and consist of three sections. The first section is a paragraph that ties the science concept for the investigation to the guiding question. The second section gives a brief description of how and why the investigation was performed, and any methods that were used to reduce error. The last section should be a full-page that answers the guiding question, discusses how the evidence led to the claim, how the science concept justified the claim, and compares the information with other groups. The third section for the general physics laboratories also needs to include information about limitations. The general physics laboratory students need to include a 4th section on their final draft that is a response to the reviewers of their paper, whereas the GC1 and GC2 students turn in hand-written responses to the reviewers. In the general chemistry laboratories, these laboratory reports go through a double-blind group peer-review process before they are graded with a standard rubric. In the general physics laboratories, the laboratory reports undergo online, individual double-blind peer-review before they are graded with the standard rubric. In GC1, the students were required to write laboratory reports for three investigations. In GC2, students wrote a laboratory report for two of the investigations. In GP1 & GP2, the students are required to write a laboratory report for all four investigations.

### Practice-Focused End-of-Course Laboratory Practical Exam

The practical exam for GC1 & GC2 was developed and refined in the traditional general chemistry laboratory course over several semesters. First, students that had completed the course were asked to take the practical exam, then the education researcher met with the students for a semi-structured interview to identify points of confusion or misinterpretation of the question. Through this process and based on students' submitted answers in the chemistry traditional laboratories, the practical exam and scoring rubric were modified to provide a practical exam that could be administered and scored reliably. All versions of the practical exam for GC1 & GC2 were submitted to chemistry faculty for expert review and changes were made based on their recommendations.

The practical exam for GP1 & GP2 was developed and refined in the traditional advanced physics laboratory course and the second semester of the calculus-based physics course (Wolf et al., 2019). The students that were in these courses were asked to take the practical exam, then the education researcher and the disciplinary researcher met with the participants and the GTA that facilitated the practical exam for an interview to identify points of confusion or misinterpretation of the questions (Wolf et al., 2019). Through this process and based on students' submitted answers in the physics traditional laboratories, the practical exam and scoring rubric were modified to provide a practical exam that could be administered and scored reliably. All versions of the practical exam for GP1 & GP2 were submitted to physics faculty for expert review and changes were made based on their recommendation (Wolf et al., 2019).

The practical exam design gave students the opportunity to demonstrate proficiency with *empirical* and *representational* science practices. When students completed the tasks on the practical exam, they demonstrated that they are able to evaluate data (*empirical* science practices) in order to make it visible to an individual or a group (*representational* science practices). The alignment of the *empirical* and *representational* science practices with the practical exam questions for each of the disciplines are presented in Appendix D.

## Scoring Validation

Pearson's correlation coefficient is used in order to test the linear relationship between two variables (Benesty et al., 2009). This value can range between -1 to 1. A positive number indicates a direct relationship and a negative number indicates an indirect relationship. The larger the number, the stronger this correlation. A coefficient greater than 0.50 indicates a strong positive correlation (Benesty et al., 2009). In this study, Pearson's correlation was used in order to determine the validity of the GTAs' scores for the first investigation laboratory reports and the practical exam. A sub-set (25%) of the first investigation laboratory reports and practical exams for GC1 & GC2 and GP1 & GP2 were randomly selected and scored by a member of the research team using the standard rubric to determine the validity of the scores by the GTAs in each of the sections. The correlation was computed to assess the relationship between the GTA and the research member scoring for each section.

It was discovered that one of the GTAs from GP1, Noon, did not use the provided standard rubric to grade work throughout the entire Fall 2018 semester. A different GTA from the physics department, recommended by physics faculty, scored all of the first investigation laboratory reports and the practical exams for the sections that were taught by Noon. A sub-set (25%) of the rescored first investigation laboratory reports and the rescored practical exams scores were then validated in the same manner as the previously described by the research team.

## Facilitation Technique Comparison

The observation protocol for all GTAs was analyzed to determine the facilitation techniques and the time allotted on relevant tasks. The scores that students received on the first investigation laboratory report were compared to determine if the students in each section of a course (e.g. GC1) were equivalent at the beginning of the semester. The students' proficiency with science practices was evaluated with scores on the practical exam. An independent samples *t*-test is used to compare the means of a variable for two different observed groups, if the means are equivalent the two samples will not vary significantly (*Wiley Online Library*, n.d.). Since the goal of this study was to determine if the difference in GTA facilitation techniques impacted the students' proficiency with science practices, an independent samples *t*-test was conducted to compare the scores on the first investigation laboratory report and the practical exam between the GTAs in each of the disciplines for each semester to determine if there were significant differences. Significant differences for the first investigation laboratory report would indicate that the students were different at the beginning of the semester. No significant difference at the beginning of the semester, with a significant difference at the end of the semester would suggest that the facilitation techniques of the GTA had impacted their students' proficiency with science practices. No significant difference at the beginning of the semester and at the end of the semester would suggest that the facilitation techniques of the GTAs did not impact their students' proficiency with science practices.

# Chapter 3. Results and Discussion

The results for the first investigation laboratory reports (Table 4) indicated that there was a high, positive correlation (>0.7, $p < 0.05$) for all sections between the GTA and the research team member. Table 4 additionally displays the means and standard deviations for both the GTAs and the research team member. The results for the Pearson's correlations of scores for the practical exam between GTAs and research members can be found in Table 5. There was also a high, positive correlation for the laboratory practical exam ($\geq 0.7$, $p < 0.05$) in all sections between each GTA and the research team member. The mean and standard deviations for the GTAs and the research team member for the laboratory practical exam in each discipline is also available in Table 5. Once the scores by the GTAs had been validated, independent-samples *t*-tests were conducted to evaluate the hypotheses that the students in the concurrent sections were equivalent at the beginning of the semester and were able to perform equivalently on a practical exam.

Table 4
*Validation of the first investigation laboratory report scores in GC1 & GC2 and GP1 & GP2*

| GTA | Subject | Correlation† | GTA *M*(SD)*** | Researcher *M(SD)* |
|---|---|---|---|---|
| Emry | GC1 | 0.9 | 43.90 (7.89) | 45.80 (8.00) |
| Nelly | GC1 | 0.9 | 45.00 (10.11) | 47.30 (10.00) |
| Emry | GC2 | 0.9 | 44.70 (5.85) | 45.80 (5.12) |
| Nelly | GC2 | 0.9 | 47.90 (11.10) | 47.50 (9.63) |
| Estlin | GP1 | 0.7 | 49.54 (9.35) | 56.23 (9.02) |
| Noon[1] | GP1 | 0.9 | 58.45 (5.46) | 58.33 (4.96) |
| Estlin | GP2 | 0.7 | 63.62 (4.74) | 60.62 (6.88) |
| Evren | GP2 | 0.7 | 71.84 (1.96) | 71.12 (3.05) |

† = significant at the 0.01 level (2-tailed), *M = mean, **SD = standard deviation
1 = Scoring for Noon's section was done by a secondary GTA with the standard rubric

Table 5
*Validation of the practical exam scores in GC1 & GC2 and GP1 & GP2*

| GTA | Subject | Correlation† | GTA *M* (SD**)* | Researcher *M(SD)* |
|---|---|---|---|---|
| Emry | GC1 | 0.9 | 37.00 (8.63) | 38.50 (10.11) |
| Nelly | GC1 | 0.9 | 40.50 (7.46) | 42.10 (6.33) |
| Emry | GC2 | 0.9 | 49.00 (9.43) | 51.80 (10.82) |
| Nelly | GC2 | 0.9 | 48.40 (9.62) | 45.50 (9.76) |
| Estlin | GP1 | 0.7 | 79.28 (7.41) | 80.39 (8.84) |
| Noon[1] | GP1 | 0.9 | 79.17 (4.62) | 79.17 (4.07) |
| Estlin | GP2 | 0.9 | 72.83 (18.98) | 72.67 (17.20) |
| Evren | GP2 | 0.9 | 80.83 (12.16) | 80.25 (11.76) |

† = significant at the 0.01 level (2-tailed), *M = mean, **SD = standard deviation
1 = Scoring for Noon's section was done by a secondary GTA with the standard rubric

## General Chemistry I

An independent samples *t*-test revealed that there was not a significant difference between the students in Emry's section (*M* = 80.03, *SD* = 9.16) and the students in Nelly's section (*M* = 80.07, *SD* = 10.37); *t* (88) = -0.016, *p* = 0.99 (Table 6) on the first investigation laboratory report. This data suggests that the students in the two sections were equivalent and were capable of writing the required laboratory reports at the beginning of the semester students in both GC1 sections.

Table 6
*Comparison of first investigation laboratory report scores in GC1*

| GTA | *t* | *Df* | *M* (SD**)* | *P* | Mean Difference | 95% Confidence Lower | 95% Confidence Upper |
|---|---|---|---|---|---|---|---|
| Emry | -0.02 | 88 | 80.03 (9.16) | 0.99 | 0.03 | -4.14 | 4.07 |
| Nelly | | | 80.07 (10.37) | | | | |

*M = *mean,* **SD = *standard deviation*

For GC1, the results from the ADI-specific observation protocol revealed that Emry consistently demonstrated *student-centered* facilitation techniques for all stages of the ADI instructional model, whereas, Nelly demonstrated facilitation techniques that were *marginal* for the data collection and data analysis stages and *student-centered* facilitation techniques for the remainder stages (Table 7). The observer witnessed Nelly providing *marginal* facilitation techniques during the first investigation for data collection and during the first two investigations for data analysis. By the third observed investigation, Nelly demonstrated *student-centered* facilitation techniques throughout all of the ADI instructional model stages.

Table 7
*GTA facilitation techniques observed for GC1*

| | Investigation 1 | | Investigation 2 | | Investigation 4 | |
|---|---|---|---|---|---|---|
| | Nelly | Emry | Nelly | Emry | Nelly | Emry |
| Proposal | | | | | | |
| Student Centered | 2 | 2 | 2 | 2 | 2 | 2 |
| Marginal | - | - | - | - | - | - |
| Instructor Centered | - | - | - | - | - | - |
| Data Collection | | | | | | |
| Student Centered | 1 | 1 | 1 | 1 | 1 | 1 |
| Marginal | 1 | - | - | - | - | - |
| Instructor Centered | - | - | - | - | - | - |
| Data Analysis | | | | | | |
| Student Centered | 1 | 1 | - | 1 | 1 | 1 |
| Marginal | 1 | - | 1 | - | - | - |
| Instructor Centered | - | - | - | - | - | - |
| Argument Development | | | | | | |
| Student Centered | - | 1 | 1 | 1 | 1 | 1 |
| Marginal | - | - | - | - | - | - |
| Instructor Centered | - | - | - | - | - | - |
| Argument Session | | | | | | |
| Student Centered | 2 | 2 | 2 | 1 | 2 | 2 |
| Marginal | - | - | - | - | - | - |
| Instructor Centered | - | - | - | - | - | - |

As previously stated, Emry had experience with the ADI instructional model as both an UTA and a GTA, whereas even though Nelly had experience with the ADI instructional model as an UTA, this was Nelly's first semester facilitating the ADI instructional model as a GTA. During the first investigation, Emry asked guiding questions that encouraged the students to build on their prior knowledge, whereas Nelly would provide a little more guidance (Table 8). For example, during the data collection stage, Emry had asked the students how many significant figures they needed and Nelly had asked students where the tenths place was with reported values. The difference in the data collection and the data analysis stages during the first investigation could be explained by the experience of the GTAs.

Table 8
*Exemplars of facilitation techniques used during the density investigation in GC1*

| Stage/GTA | Behavior |
|---|---|
| **Data Collection** | |
| Emry | GTA showed students the +/- 0.04 mL on the pipette and asked how many decimal places they thought they needed for significant figures. |
| Nelly | GTA asked a group where their tenths value was when a student showed their values for the graduated cylinder. |
| **Data Analysis** | |
| Emry | GTA would respond to any student questions with a guiding question without providing a direct answer. |
| Nelly | GTA told students that initial volume and final volume were data, but the change in volume was their evidence. |

The practical exam scores were compared between the GTAs with an independent-samples *t*-test to determine if the difference in the facilitation techniques during the semester impacted student's proficiency with science practices. There was no significant difference between the students in Emry's (M = 71.27, SD = 14.60) and Nelly's (M = 77.43, SD = 15.67) sections for the practical exam scores; $t$ (88) = -1.927, p = 0.06. Figure 2 shows the distributions and the means for the practical exam for the two sections in GC1. In order to be considered a data point for this research, students had to submit the first investigation laboratory report and provide an answer to all of the questions on the practical exam. Figure 2 indicates that there were two outliers in Nelly's section. These students had answered all of the questions on the practical exam. For this reason, the students were included in the data set.

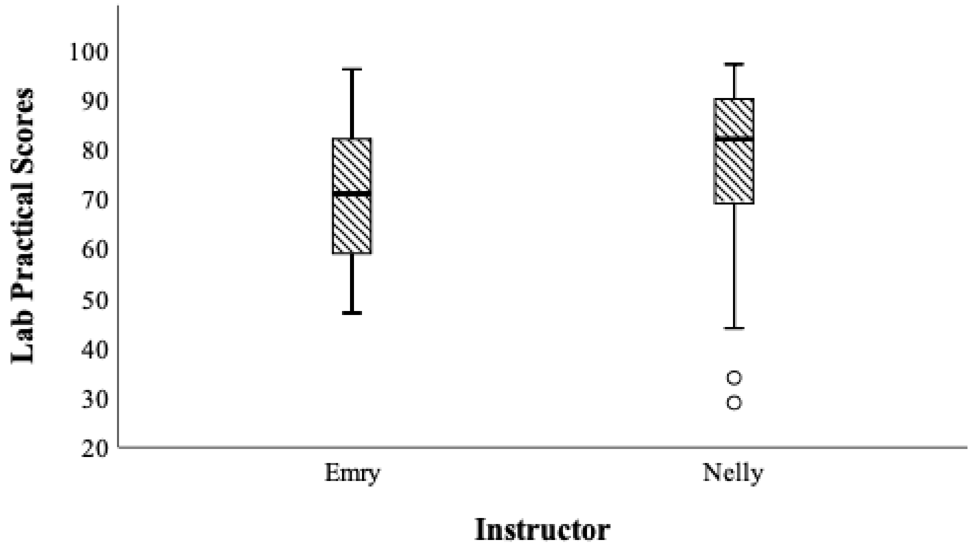


*Figure 2*. Comparison of practical exam scores in GC1 by graduate teaching assistant.

## General Chemistry II

An independent samples *t*-test revealed that there was not a significant difference between the students in Emry's section (*M* = 81.48, *SD* = 8.19) and the students in Nelly's section (*M* = 85.85, *SD* = 11.03); *t* (66) = -1.76, *p* = 0.08 (Table 9) on the first investigation laboratory report. This data suggests that the students in the two sections were equivalent and were capable of writing the required laboratory reports at the beginning of the semester students in both GC2 sections.

Table 9
*Comparison of first investigation laboratory report scores in GC2*

| GTA | Subject | *T* | *df* | *M (SD)* | *P* | Mean Difference | 95% Confidence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lower | Upper |
| Emry<br>Nelly | GC2<br>GC2 | -1.76 | 66 | 81.48 (8.19)<br>85.85 (11.03) | 0.08 | 4.37 | -9.33 | 0.58 |

With the exception of demonstrating marginal facilitation techniques during the buffer titration investigation (last investigation observed of GC2), the results from the ADI-specific observation protocol revealed that Emry demonstrated student-centered facilitation techniques throughout the entire semester of GC2 (Table 10). The observer witnessed marginal facilitation techniques by Nelly during data collection and data analysis throughout the semester, and during the last investigation for the argument development and during the argumentation session (Table 10). Nelly demonstrated instructor-centered facilitation techniques for the data collection and analysis stages of the buffer titration investigation (last investigation observed of GC2).

Table 10
*GTA facilitation techniques observed for GC2*

| | Investigation 1 | | Investigation 2 | | Investigation 4 | |
|---|---|---|---|---|---|---|
| | Nelly | Emry | Nelly | Emry | Nelly | Emry |
| Proposal | | | | | | |
| Student Centered | 2 | 2 | 2 | 2 | 2 | 1 |
| Marginal | - | - | - | - | - | - |
| Instructor Centered | - | - | - | - | - | - |
| Data Collection | | | | | | |
| Student Centered | 1 | 1 | 1 | 1 | 1 | 1 |
| Marginal | - | - | 1 | - | 2 | 1 |
| Instructor Centered | - | - | - | - | - | - |
| Data Analysis | | | | | | |
| Student Centered | 1 | 1 | 1 | 1 | 1 | 1 |
| Marginal | - | - | 1 | - | 1 | - |
| Instructor Centered | - | - | - | - | 1 | - |
| Argument Development | | | | | | |
| Student Centered | 1 | 1 | 1 | 1 | 1 | 1 |
| Marginal | - | - | - | - | - | 1 |
| Instructor Centered | - | - | - | - | - | - |
| Argument Session | | | | | | |
| Student Centered | 2 | 2 | 2 | 2 | 1 | 2 |
| Marginal | - | - | - | - | 1 | - |
| Instructor Centered | - | - | - | - | - | - |

Emry had previously facilitated GC2 as a GTA with the ADI instructional model, whereas, Nelly had only facilitated GC1 for one semester as a GTA prior to being observed facilitating GC2. The buffer titration investigation had undergone some changes for the semester observed, which could explain the variations in facilitation techniques from both GTAs during this investigation. Emry had assisted one group with the calibration of their probe after the group had struggled to do so, whereas, Nelly had shown the students in that section how to setup the apparatus (Table 11). Nelly had also demonstrated some *instructor-centered* facilitation techniques during the data analysis stage with one group for the buffer titration investigation. Although both GTAs demonstrated a variation in facilitation techniques, the less experienced GTA had reverted to *instructor-centered* facilitation techniques when faced with a change in the curriculum.

Table 11 shows exemplars of the facilitation techniques by the GC2 GTAs for the stages of the ADI instructional model during the buffer titration investigation. For example, during the data collection stage, Emry asked the groups in their section how much acid was a reasonable amount and allow the students to answer, whereas, Nelly told the groups how much acid to use. Since the independent samples *t*-test revealed that there was no significant difference in the practical exam scores between these two sections, it does not appear that *instructor-centered* facilitation techniques during the last investigation of the semester impacted the students' proficiency as measured by the laboratory practical exam.

Table 11

*Exemplars of facilitation techniques used during the buffer titration investigation in GC2*

| Stage/GTA | Behavior |
|---|---|
| **Data Collection** | |
| Nelly | The GTA told the students what file to open, how to set up the apparatus, and how much acetic acid they should use.<br>The GTA asked the groups what was going to happen to the pH when they added $OH^-$ to the beaker and what happened in the beaker when they added $OH^-$ |
| Emry | The GTA asked the students "what do you think is a reasonable amount?" if a group asked how much acid they should use. |
| **Data Analysis** | |
| Nelly | The GTA told the students to do the necessary calculations with the amount of volumes they had used and that they needed to subtract the initial volume from the final volume before converting to moles. |
| Emry | The GTA would ask the groups what chemical species were present in each region of the titration curve. |
| **Argument Development** | |
| Nelly | During the buffer investigation, the GTA generally explained the parts of the whiteboard to the groups as they developed their argument. |
| Emry | The GTA walked around the room as the students worked on their whiteboard. |
| **Argumentation Session** | |
| Nelly | The GTA told a group that had stated the middle region of their titration curve was their buffer region "that's wrong" and asked what buffers do and then asked the travelers what area they thought was the buffer region. When the travelers looked at the data and began discussing it, the GTA walked away. |
| Emry | The GTA asked the travelers if they had gotten the similar results to a group that was not asking the presenter questions. The travelers then started discussing parts of the whiteboard. |

The independent-samples *t*-test revealed that the student mean scores on the practical exam in GC2 were not significantly different, $t$ (66) = -0.85 and suggested that the students' proficiency with science practices in Nelly's section ($M$ = 74.49, $SD$ = 12.26) and in Emry's section ($M$ = 71.93, $SD$ = 12.00), $p$ = 0.40, were equivalent at the end of the semester. Figure 3 shows the distributions and the means for the practical exam for the two sections in GC2.

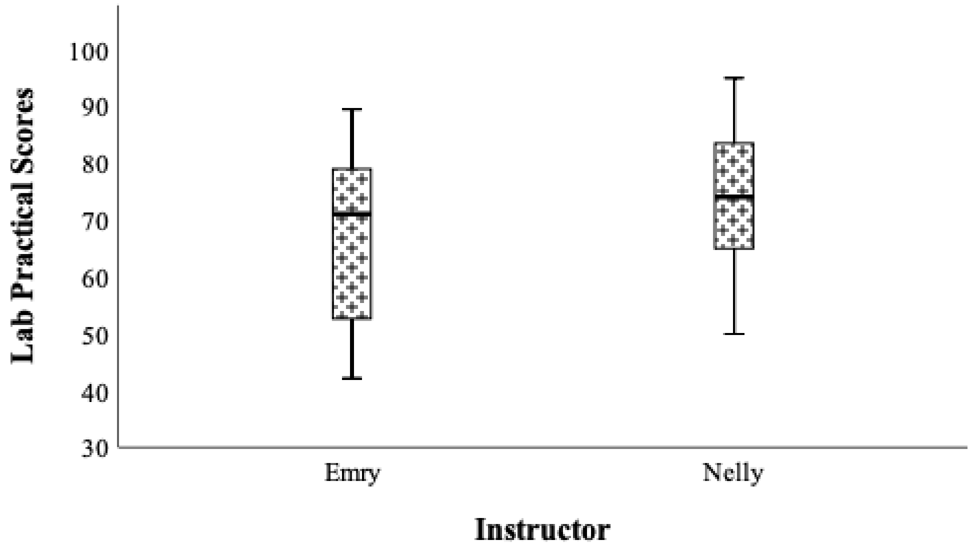


*Figure 3.* Comparison of practical exam scores in GC2 by graduate teaching assistant.

## General Physics I

An independent samples *t*-test revealed that there was not a significant difference between the students in Noon's sections (*M* = 75.25, *SD* = 8.85) and the students in Estlin's section (*M* = 75.42, *SD* = 11.05); *t* (113) = 0.39, *p* = 0.70 (Table 12) for the first investigation laboratory report scores. This data suggests that the students in the two sections were equivalent and were capable of writing the required laboratory reports at the beginning of the semester in both GP1 sections.

Table 12
Comparison of first investigation laboratory report scores in GP1

| GTA | Subject | *T* | *Df* | *M (SD)* | *P* | Mean Difference | 95% Confidence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lower | Upper |
| Estlin<br>Noon | GP1<br>GP1 | 0.39 | 113 | 74.52 (11.05)<br>75.42 (8.85) | 0.70 | 0.73% | -2.97 | 4.43 |

The results from the ADI-specific observation protocol revealed that Noon demonstrated *marginal* techniques during data collection and analysis as well as *instructor-centered* techniques during developing a proposal, argumentation session, data collection stages (Table 13) throughout the entire semester. For these stages, Estlin demonstrated *marginal* techniques during the first investigation and *student-centered* techniques during the remainder of the investigations (Table 13).

Table 13
GTA facilitation techniques observed for GP1

| | Investigation 1 | | Investigation 2 | | Investigation 4 | |
|---|---|---|---|---|---|---|
| | Noon | Estlin | Noon | Estlin | Noon | Estlin |
| Proposal | | | | | | |
| Student Centered | 2 | 2 | 2 | 2 | 2 | 2 |
| Marginal | - | - | - | - | - | - |
| Instructor Centered | 1 | - | - | - | 1 | - |
| Data Collection | | | | | | |
| Student Centered | 1 | 1 | 1 | 1 | 1 | 1 |
| Marginal | 1 | 1 | - | - | 1 | - |
| Instructor Centered | - | - | - | - | 1 | - |
| Data Analysis | | | | | | |
| Student Centered | 1 | 1 | 1 | 1 | 1 | 1 |
| Marginal | - | 1 | - | 1 | 1 | - |
| Instructor Centered | - | - | - | - | - | - |
| Argument Development | | | | | | |
| Student Centered | 1 | 1 | 1 | 1 | 1 | 1 |
| Marginal | - | - | - | - | - | - |
| Instructor Centered | - | - | - | - | - | - |
| Argument Session | | | | | | |
| Student Centered | 2 | 2 | 1 | 2 | 2 | 2 |
| Marginal | - | 1 | - | - | - | - |
| Instructor Centered | - | - | 1 | - | 1 | - |

Estlin had assisted with the pilot section of GP1 with the ADI instructional model and had facilitated 2 semesters of GP1 with the traditional laboratory model prior to being observed during the semester of full implementation. Noon had previously facilitated 10 semesters of the traditional model of GP1. After Noon had left the laboratory room several times for ~10 minutes and demonstrated undesirable facilitation techniques, intervention was provided by the lab manager. Noon continued to demonstrate *instructor-centered* facilitation techniques after the intervention. Exemplars of the facilitation techniques by the GP1 GTAs for the developing a proposal, data collection, and argumentation session of the 1D motion investigation are located in Table 14. These three stages had the most variance between the GTAs during the semester.

Table 14
*Exemplars of facilitation techniques used during the 1D motion investigation in GP1*

| **Stage/GTA** | **Behavior** |
|---|---|
| **Proposal** | |
| Noon | GTA told students to document what fan setting and how many weights they used. |
| Estlin | GTA asked students what they were measuring when an issue was spotted with the proposal. |
| **Data Collection** | |
| Noon | GTA was disengaged, unavailable to the students, and was working on homework for another class. |
| Estlin | GTA was observing the groups from the front of the room and was available if the students needed assistance. |
| **Argumentation Session** | |
| Noon | GTA asked the presenter about their data (acceleration & mass) and then stated that they analyzed the data wrong.<br>GTA questioned a presenter about velocity, mass, trials, and error. The travelers listened to the GTA talk, but did not ask any questions until the GTA had gone to another group. |
| Estlin | GTA mentioned how quiet the room was and then prompted the travelers to find errors on the whiteboard and have the presenter fix them.<br>The GTA handed a 1 kg weight when the student stated the force was ~75 N. The GTA explained that the weight was ~10 N with gravity and then asked the presenter & travelers what units were in a N. |

An independent *t*-test was conducted to evaluate the hypothesis that the means and the distributions of the practical exam scores were the same across both GTAs. The results of the test indicated that there was a significant difference, between the students' scores in Estlin's sections ($M = 86.36$, $SD = 9.65$) and the students' rescored scores in Noon's sections ($M = 70.28$, $SD = 13.11$), $p < 0.001$. Figure 4 shows the distributions of the scores on the practical exam for the two sections for GP1. Figure 4 indicates that there was one outlier in Estlin's section. This student had answered all of the questions on the practical exam. For this reason, the student was included in the data set.

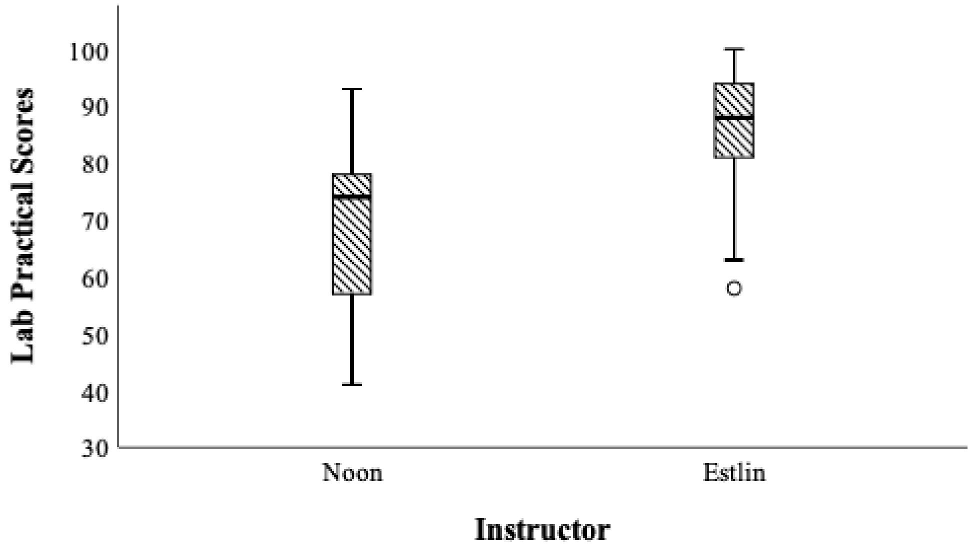


*Figure 4*. Comparison of practical exam scores in GP1 by graduate teaching assistant.

After the semester was over, it was discovered that Noon had not used the standard rubrics throughout the entire semester. Since the standard rubric was not being used, it is possible that the students in Noon's sections were not aware of what was required of them and this might have hindered the students in developing science practices. This could have led to the significant difference between the students in Noon's sections and the students in Estlin's sections. Students in Estlin's sections performed better on the practical exam than did the students in Noon's sections. Upon examination of the rubrics, all of the students in Noon's section assumed the mass on the weights were correct, whereas, students in Estlin's section used a balance to determine the mass of the weights.

**General Physics II**

An independent-samples *t*-test revealed that there was not a significant difference between the students in Estlin's sections ($M$ = 77.88, $SD$ = 13.92) and the students in Evren's sections ($M$ = 82.30, $SD$ = 10.64), $p$ = 0.59 (Table 15) on the first investigation laboratory report. This data suggests that the students in the two sections were equivalent and were capable of writing the required laboratory reports at the beginning of the semester in both GP2 sections.

Table 15
*Comparison of first investigation laboratory report scores in GP2*

| **GTA** | ***t*** | **Df** | ***M (SD)*** | ***p*** | **Mean Difference** | **95% confidence** | |
|---|---|---|---|---|---|---|---|
| | | | | | | **Lower** | **Upper** |
| Estlin | -1.78 | 94.92 | 88.04 (11.04) | 0.59 | 4.42 | -9.35 | 0.51 |
| Evren | | | 88.98 (5.69) | | | | |

The ADI-specific observation protocol revealed that Estlin demonstrated *marginal* facilitation techniques during the first two investigations for both data collection and analysis and for the whole semester during the argumentation session (Table 16). Whereas Evren demonstrated *instructor-centered* facilitation techniques during the proposal and *marginal* & *instructor-centered* facilitation techniques during the optics investigation and *student-centered* facilitation techniques for the remainder of the observations (Table 16).

Table 16

*GTA facilitation techniques observed for GP2*

| | Investigation 1 | | Investigation 2 | | Investigation 4 | |
|---|---|---|---|---|---|---|
| | Estlin | Evren | Estlin | Evren | Estlin | Evren |
| Proposal | | | | | | |
| Student Centered | 2 | 2 | 2 | 2 | 2 | 2 |
| Marginal | - | - | - | - | - | - |
| Instructor Centered | - | - | - | 1 | - | - |
| Data Collection | | | | | | |
| Student Centered | 1 | 1 | 1 | 1 | 1 | 1 |
| Marginal | 1 | - | 1 | - | - | - |
| Instructor Centered | - | - | - | - | - | - |
| Data Analysis | | | | | | |
| Student Centered | 1 | 1 | 1 | 1 | 1 | 1 |
| Marginal | - | - | 1 | 1 | - | - |
| Instructor Centered | - | - | - | 1 | - | - |
| Argument Development | | | | | | |
| Student Centered | 1 | 1 | 1 | 1 | 1 | 1 |
| Marginal | - | - | - | - | - | 1 |
| Instructor Centered | - | - | - | - | - | - |
| Argument Session | | | | | | |
| Student Centered | 2 | 2 | 2 | 2 | 1 | 2 |
| Marginal | 1 | - | 1 | - | 1 | - |
| Instructor Centered | - | - | - | - | - | - |

In GP2, Evren had assisted with the pilot section of the ADI instructional model prior to being observed and Estlin had only facilitated GP1 with the ADI instructional model. Evren had also facilitated 8 semesters of the traditional laboratory model and 6 semesters at an institution using an active learning model that would have 10 minutes of lecture followed by an activity that students worked on in groups. Both of the GTAs demonstrated the most variance from student-centered facilitation techniques during the optics investigation. This is possibly due to the equipment arriving right before the investigation took place and the GTAs did not have time to perform the investigation themselves beforehand. Prior to the equipment arriving, both the GTAs and the students were prepared to do a different investigation. There was no significant difference in the practical exam between these two sections; for the majority of the semester both GTAs provided *student-centered* facilitation techniques consistently for the stages of the ADI instructional model. Exemplars of the differences between the GTAs during the stages of the optics investigation can be found in Table 17. For example, during the data analysis stage Estlin had told a group that what they had given for error was the error in the markings on the yardstick and not the error in the measurement itself, whereas, Evren told the students to look at the data for each hair with its uncertainty and if there was any overlap the hairs were the same thickness.

Table 17
*Exemplars of facilitation techniques used during the optics investigation in GP2*

| Stage/GTA | Behavior |
|---|---|
| **Proposal** | |
| Estlin | While looking at a group's proposal, the GTA asked the students what equation they would be using and how they knew that equation was valid. When the group mentioned Babinet's Principle, the GTA would let them set up their investigation. |
| Evren | The GTA drew an outline on the blackboard of how the groups would be setting up their investigation and provided a proposal checklist. The GTA discussed in detail what the students would need to include in their proposal and told them to make sure their proposal contained all elements. |
| **Data Collection** | |
| Estlin | The GTA noticed a group used both the green and the red laser and told the students they would have to statistically combine the uncertainties if they used both lasers for the investigation.<br>One group asked the GTA how they were supposed to measure their minima when they had about 100 and the GTA responded "you'll have to change something about your set-up" and walked away. The group moved the apparatus further back and were able to measure the distance between the dark spots. |
| Evren | The GTA asked the students if it would be better to measure 2 hairs twice or 3 hairs once in order to answer the guiding question and which laser gave more reliable data and why, and how they were going to reduce error. |
| **Data Analysis** | |
| Estlin | The GTA asked a group how they had gotten 0.001 cm for their error in distance. When the group responded that they had looked it up, the GTA told them "that may be the error for where the lines are but that isn't the error in making the measurement." The GTA then asked the group how they would get the error in measurement, when the group said standard deviation, the GTA asked what they would calculate next and the group responded standard error. |
| Evren | Several groups struggled with calculating percent difference, so the GTA told the students to use the equation from the lab manual to calculate the hair's uncertainty instead of percent difference. The GTA told the students to look at each hair with the associated uncertainty and if there was any overlap the hairs were the same thickness. |
| **Argumentation Session** | |
| Estlin | One group had a hair diameter listed as $10^{-8}$ with an uncertainty of $10^{-5}$, the GTA drew a number line on their whiteboard to demonstrate that they had a negative diameter and then asked "does that make sense?" When the students said "no", the GTA said "maybe you calculated something wrong." |
| Evren | The GTA listened to the student's presentation and the travelers' questions and then moved on to the next group without interjection. A couple groups attempted to travel together and the GTA sent them to the correct presentations. |

An independent-samples *t*-test was performed to determine if the difference in the facilitation techniques by the GTAs throughout the semester impacted the students' ability to demonstrate science practices on the practical exam. There was no significant difference for the student scores in Evren's sections (*M* = 82.30, *SD* = 10.64) and in Estlin's sections (*M* = 77.88, *SD* = 13.92), *t* (94.92) = -1.78, p = 0.08. This suggests that the students in Evren's section and Estlin's section were equivalent at the end of the semester. Figure 5 shows the distributions of the scores on the practical exam for the two sections for GP1. Figure 5 indicates that there was one outlier in Evren's section. This student had answered all of the questions on the practical exam. For this reason, the student was included in the data set.

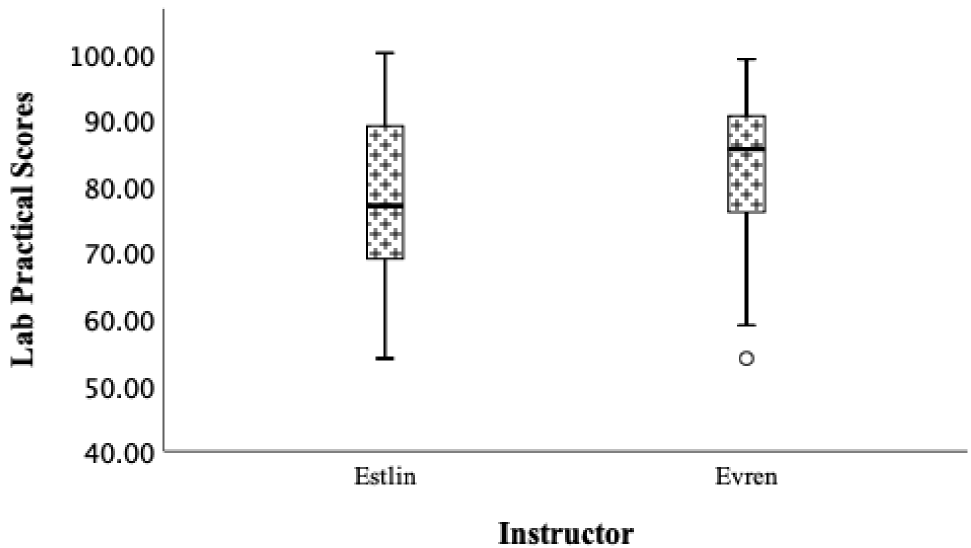


*Figure 5*. Comparison of practical exam scores in GP2 by graduate teaching assistant.

# Chapter 4. Conclusions & Implications

This study suggests *marginal* facilitation techniques and a few instances of *instructor-centered* facilitation techniques by graduate teaching assistants do not impact the development of students' science practices within a laboratory course. Consistent *instructor-centered* facilitation techniques, as observed in Noon's section of GP2, may have an impact on students' development of science practices. There was not a significant impact to the students' proficiency with science practices in the sections that the GTAs provided primarily *student-centered* facilitation techniques with some occurrences of *marginal* and *instructor-centered* facilitation techniques for the ADI instructional model throughout the semester. The importance of GTAs using the established rubrics when scoring student work throughout the semester in order to assist students with developing important science practices will be emphasized in future training events. This study suggests that failure to use the rubrics combined with consistent *instructor-centered* facilitation techniques, may result in students not being able to demonstrate that they know how to use these science practices.

Students in each of the courses were able to demonstrate their proficiency with science practices on the practical exam. Even though there were differences in facilitation techniques between the GTAs in all of the disciplines, there was only a significant difference in the students' scores on the practical exam between GTA sections in GP1. This suggests that the ADI curriculum facilitates student development of science practices, which was demonstrated previously. These results indicate that it is not necessary for GTAs to be observed throughout the entire semester to make sure that their facilitation techniques align with the ADI instructional model.

For GP1, Noon's implementation of the ADI instructional model was not consistent throughout the semester. After the first investigation, the physics lab manager was made aware of the researcher's concerns and intervention was attempted. Noon continued to demonstrate *instructor-centered* facilitation techniques after feedback was provided. After the semester was over, it was discovered that Noon had not used the standard rubrics throughout the semester. Noon had complained to the researcher several times throughout the semester about the amount of grading that was required of the GTAs with the ADI format. In order for a GTA to be successful facilitating inquiry-based curriculum they need to believe teaching the inquiry model is valuable (Wheeler et al., 2019). Noon's refusal to use standard rubrics to grade students' work, observations of the laboratory, and comments made to the researcher about the amount of work indicates that Noon's experience with the ADI format was not favorable and supports previous research that in order to be successful with inquiry-based curriculum, GTAs must believe the method is valuable (Wheeler et al., 2019). Lack of use of the provided rubrics, resulted in the students in Noon's sections not knowing what was expected of them which led to the students in Noon's sections to have a lower proficiency with science practices as measured on the practical exam than the students in Estlin's sections for GP1. Noon's lack of using the standard rubrics has led to the faculty in the physics department auditing the grading of laboratory reports and the practical exam for GP1 & GP2. The results from GP1support previous research that feedback encourages learning when each student is provided feedback on the strengths and weaknesses of their work (Black & William, 2010).

Noon's claim that the ADI instructional model required more grading is not supported since the majority of the work is group work for the exception of the four laboratory reports. In the previous model at this institution, the students would work on investigations in pairs and would turn in individual reports that the GTAs graded without standard rubrics. Therefore, in the previous model the GTAs would grade twelve assignments weekly as compared to six assignments in the ADI format. The proposals for the ADI format are done in class and are not approved until the groups include all of the required information. The GTAs do not grade the whiteboard posters, in fact the only graded material in GP1 & GP2 are the pre-labs from the first week of an investigation and the written laboratory reports from the fourth week of an investigation.

It is likely that Noon having taught ten semesters of the traditional style laboratory led to their reliance on *instructor-centered* facilitation techniques. Only one other GTA, Evren, had taught more than five semesters of the traditional laboratory model. Perhaps, Evren did not demonstrate *instructor-centered* facilitation techniques due to facilitating six semesters of an active classroom prior to facilitating the ADI instructional model. Previous research indicates that GTAs with a previous positive experience with traditional based laboratories tend to revert back to *instructor-centered* facilitation techniques and can see students struggle with the curriculum as a negative side-effect of inquiry-based laboratories, whereas GTAs that had positive inquiry-based experiences view student struggles as a necessary part of the learning process (Wheeler et al., 2019). Noon's ten semesters facilitating traditional laboratories might have been a positive experience for Noon and could explain why Noon consistently demonstrated *instructor-centered* facilitation techniques which would support the previous findings in literature. The novice GTAs also reverted back to *instructor-centered* facilitation techniques when there was an unexpected change in the curriculum (i.e. the buffer investigation in GC2), whereas their counterpart demonstrated *marginal* facilitation techniques during last minute changes.

**Limitations**

During the Fall 2018 semester, the university was closed for eight days due to a natural disaster during the first investigation. The laboratories during this semester were adapted and the students in GC1 only wrote two laboratory reports. The practical exam requires the students to perform an investigation and write an argument, therefore this change could have impacted the students' science practice proficiency.

In the GC1 & GC2 laboratories there is a second GTA or a UTA that assists the Senior GTA. Since there was only one observer and the observations were done during the laboratory period, only the senior GTA was observed. Some of the GC1 & GC2 laboratories also have a UTA shadow. The UTA shadows take a course for credit that shows them how to be an effective UTA with the ADI instructional model. These UTA shadows were also not observed during this study. Therefore, the potential impact of the secondary instructors in the laboratory is not evaluated in this study. Any interactions that occurred between the GTAs & UTAs with their students outside of the laboratory were not studied during this research.

The length of laboratory courses varied between chemistry (3 hrs) and physics (2 hrs). For this reason, there was some variation in implementation between the disciplines. Both courses participate in a double-blind peer-review, however, in chemistry the students perform an in-class group peer-review and in physics the students participate in an individual online peer-review. The other main difference is the argumentation session and post argumentation-discussion stages. In chemistry, these stages are performed at the end of the three-hour laboratory, whereas in physics the students perform the argumentation session during the third week of class and are given time to collect more data after the argumentation session if they feel it is necessary.

Observer effect also acts as a limitation. It was noticed while the ADI-specific observation protocol was being developed, some instructors were interested in what the observer was writing down. To minimize this effect, the observer in this study would take notes out of view from the GTAs. If students attempted to ask the observer for assistance, the observer would inform the students that they needed to ask the GTA and that the observer would not be able to answer any questions.

## References


Addy, T. M., & Blanchard, M. R. (2010). The Problem with Reform from the Bottom up: Instructional practises and teacher beliefs of graduate teaching assistants following a reform-minded university teacher certificate programme. *International Journal of Science Education*, *32*(8), 1045–1071. https://doi.org/10.1080/09500690902948060

Benesty, J., Chen, J., Huang, Y., & Cohen, I. (2009). Pearson Correlation Coefficient. In I. Cohen, Y. Huang, J. Chen, & J. Benesty, *Noise Reduction in Speech Processing* (Vol. 2, pp. 1–4). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-00296-0_5

Black, P., & William, D. (2010). Inside the Black Box: Raising Standards through Classroom Assessment. *Sage Publishing*, *92*(1), 81–90.

Bruck, A. D., & Towns, M. (2013). Development, implementation, and analysis of a national survey of faculty goals for undergraduate chemistry laboratory. *Journal of Chemical Education*, *90*(6), 685–693.

Burke, K., Hand, B., Poock, J., & Greenbowe, T. (2005). Using the Science Writing Heuristic: Training chemistry teaching assistants. *Journal of College Science Teaching*, *September*, 31–46.

Ford, M. J. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education*, *92*(3), 404–423.

National Research Council. (2012). *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering. A report prepared by the Committee on the Status, Contributions, and Future Directions of Discipline-Based Education Research Board on Science Education, Division of Behavioral and Social Sciences and Education.* (N. A. Press, Ed.). National Research Council.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*.

*Peergrade—Engaging student peer review*. (n.d.). Peergrade - Engaging Student Peer Review. Retrieved February 11, 2020, from https://www.peergrade.io/

Reid, N., & Shah, I. (2007). The role of laboratory work in university chemistry. *Chemistry Education Research and Practice*, *8*(2), 172–185.

*Robustness of the two independent samples t-test when applied to ordinal scaled data—Heeren—1987—Statistics in Medicine—Wiley Online Library*. (n.d.). Retrieved January 20, 2020, from https://onlinelibrary.wiley.com/doi/abs/10.1002/sim.4780060110

Sawada, D., Piburn, M. D., Judson, E., Turley, J., Falconer, K., Benford, R., & Bloom, I. (2002). Measuring Reform Practices in Science and Mathematics Classrooms: The Reformed Teaching Observation Protocol. *School Science and Mathematics*, *102*(6), 245–253. https://doi.org/10.1111/j.1949-8594.2002.tb17883.x

Velasco, J. B., Knedeisen, A., Xue, D., Vickrey, T. L., Abebe, M., & Stains, M. (2016). Characterizing Instructional Practices in the Laboratory: The Laboratory Observation Protocol for Undergraduate STEM. *Journal of Chemical Education*, *93*(7), 1191–1203. https://doi.org/10.1021/acs.jchemed.6b00062

Walker, Joi P., & Sampson, V. (2013). Learning to argue and arguing to learn: Argument-driven inquiry as a way to help undergraduate chemistry students learn how to construct arguments and engage in argumentation during a laboratory course. *Journal of Research in Science Teaching*, *50*(5), 561–596.

Walker, Joi P., Sampson, V., Grooms, J., Zimmerman, C., & Anderson, B. (2012). Argument-driven inquiry in undergraduate chemistry labs: The impact on students' conceptual understanding, argument skills, and attitudes toward science. *Journal of College Science Teaching*, *41*(4), 74–81.

Walker, Joi P., Sampson, V., & Zimmerman, C. (2011). Argument-driven inquiry: An introduction to a new instructional model for use in undergraduate chemistry labs. *Journal of Chemical Education*, *88*(10), 1048–1056.

Walker, Joi Phelps, Sampson, V., Southerland, S., & Enderle, P. J. (2016). Using Laboratory to Engage All Students in Science Practices. *Chem. Educ. Res. Pract.*, *17*, 1098–1113. https://doi.org/10.1039/C6RP00093B

Wheeler, L. B., Chiu, J. L., Maeng, J. L., & Bell, R. L. (2019). An exploratory study of teaching assistants' motivation for inquiry-based teaching in an undergraduate laboratory context. *Chemistry Education Research and Practice*, *20*(1), 53–67. https://doi.org/10.1039/C8RP00157J

Wheeler, L. B., Clark, C. P., & Grisham, C. M. (2017). Transforming a Traditional Laboratory to an Inquiry-Based Course: Importance of Training TAs when Redesigning a Curriculum. *Journal of Chemical Education*, *94*(8), 1019–1026. https://doi.org/10.1021/acs.jchemed.6b00831

Wilcox, M., Kasprzyk, C. C., & Chini, J. J. (2015). Observing Teaching Assistant Differences in Tutorials and Inquiry-Based Labs. *2015 Physics Education Research Conference Proceedings*, 371–374. https://doi.org/10.1119/perc.2015.pr.088

Wilcox, M., Yang, Y., & Chini, J. J. (2016). Quicker method for assessing influences on teaching assistant buy-in and practices in reformed courses. *Physical Review Physics Education Research*, *12*(2), 020123. https://doi.org/10.1103/PhysRevPhysEducRes.12.020123

Wolf, S., Sprague, M., Li, F., Smith-Joyner, A., & Walker, J. P. (2019). Introductory physics laboratory practical exam development: Investigation design, explanation, and argument. *The PER Conference Proceedings*. Physics Education and Research Conference, Provo, UT.

*Women, Minorities, and Persons with Disabilities in Science and Engineering: 2015* (Special Report NSF No. 15–311). (2015). National Science Foundation, National Center for Science and Engineering Statistics. http://www.nsf.gov/statistics/wmpd/

# APPENDIX A: IRB AMENDMENT

**EAST CAROLINA UNIVERSITY**
**University & Medical Center Institutional Review Board**
**252-744-2914 252-744-2284**
[www.ecu.edu/ORIC/irb](www.ecu.edu/ORIC/irb)

## Notification of Amendment Approval

| | |
|---|---|
| From: | Social/Behavioral IRB |
| To: | Joi Walker |
| CC: | |
| | Joi Walker |
| Date: | 9/24/2018 |
| Re: | Ame4_UMCIRB 17-001117<br>UMCIRB 17-001117<br>XLABS |

Your Amendment has been reviewed and approved using expedited review for the period of 9/22/2018 to 1/28/2019. It was the determination of the UMCIRB Chairperson (or designee) that this revision does not impact the overall risk/benefit ratio of the study and is appropriate for the population and procedures proposed.

Please note that any further changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. A continuing or final review must be submitted to the UMCIRB prior to the date of study expiration.The investigator must adhere to all reporting requirements for this study.

Approved consent documents with the IRB approval date stamped on the document should be used to consent participants (consent documents with the IRB approval date stamp are found under the Documents tab in the study workspace).

The approval includes the following items:

| Document | Description |
|---|---|
| Biology Identity Survey.docx(0.01) | Surveys and Questionnaires |
| Chemistry Identity Survey.docx(0.01) | Surveys and Questionnaires |
| ConsentFormObservation.docx(0.01) | Consent Forms |
| Physics Identity Survey.docx(0.01) | Surveys and Questionnaires |

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

*Figure 6.* IRB amendment for research

# APPENDIX B: PERMISSION LETTER

***X-Labs: Cross-Disciplinary Practice Focused Undergraduate Laboratory Transformation***

You are invited to participate in a research study that is designed to examine the impact of a laboratory instruction that is designed to improve the science proficiency of undergraduate science students. You were selected as a possible participant because you are the instructor of an undergraduate science laboratory course. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

The overall goal of this study is to document how undergraduate students' knowledge, skills, and attitudes toward science change over the course of a semester and between three disciplines (biology, chemistry and physics) in response to the laboratory instructional model. Dr. Joi Phelps Walker is the principal investigator for this study. She is an Assistant Professor of Chemistry at East Carolina University.

If you choose to participate in this study, you are giving the research team permission to use a protocol to observe and document your laboratory instruction as part of data for this study. You may be observed in some or all your laboratory sessions. The observation of each laboratory session will take place for a part of or the whole laboratory session. These observational data will not be seen by anyone outside the research team.

Your participation in this study will involve no additional work or time on your part other than what you already completed as part of this class. The information provided by you during this study will be used to evaluate the impact of laboratory instruction on undergraduate science learning.

There are no risks, or direct benefits, from your participation in this study. However, your participation in this study will enable us to improve undergraduate science education.

The records of this study will be kept private and confidential to the extent allowed by law. We are asking you to provide identifying information. However, your responses will be kept confidential. No data will be released or used with your identification attached. Research records will be stored securely and only members of my research team will have access to the records. We will keep the copies of your observation protocol with data in a locked file cabinet or password protected computer. These materials will be destroyed three years after the completion of this research project, which is July 31, 2023.

Participation in this study is voluntary. Your decision whether or not to participate will not affect your current and future relations with East Carolina University or the Chemistry Department. If you decide to participate, you are free to withdraw at any time without affecting those relationships.

In addition, the fact that your supervisor might be upset with you may make you feel like you have to participate in the study. You do not have to participate if you do not want to. In fact, your supervisor will not know if you agreed to participate or not. Once again, your participation in this study is completely voluntary and choosing to or not to participate in this study will not influence your supervisor's opinion of you, or your current or future relationship with ECU.

You may ask any question you have now. If you have a question later, you are encouraged to contact Dr. Joi Walker at:

Department of Chemistry
Science and Technology Bldg. Room 503
East Carolina University
(328) 252-9772
walkerjoi15@ecu.edu

You may also contact the Office of Research Integrity & Compliance (ORIC) at 252-744-2914 for questions about your rights as a research participant.

*Figure 7*. Permission letter signed by observed GTAs

## APPENDIX C: ADI-SPECIFIC OBSERVATION PROTOCOL

Course:_____________________ Day/Time:___________________ Instructor:______________

| SC/IC* | Instructional Component | Observed |
|---|---|---|
| | **Pre-Lab** | |
| | Lab safety discussed | |
| | Basic concepts pertaining to lab | |
| | Sample calculations or statistics | |
| | Suggestions for data collection. | |
| | Suggestions for data analysis | |
| | **Developing a Proposal** | |
| SC | Instructor asks guiding questions | |
| ↓ | Instructor checks on whole class progress | |
| ↓ | Instructor explicitly answers all questions | |
| IC | Instructor outlines the procedure | |
| | **Collection of Data** | |
| SC | Instructor checks on whole class progress | |
| ↓ | Instructor checks on group progress | |
| ↓ | Instructor gives some aid and offers suggestions in data collection | |
| ↓ | Instructor interjects and directs data collection | |
| ↓ | Instructor demonstrates how to collect data specifically | |
| IC | Instructor helps assess validity of data | |
| | **Analysis of Data** | |
| SC | Instructor allows students to independently analyze data | |
| ↓ | Instructor gives some aid and offers suggestions in data analysis | |
| IC | Instructor leads description of proper data analysis and calculations in stepwise fashion. | |
| | **Development of Tentative Argument** | |
| SC | Instructor floats to groups and monitors argument development without explicit direction | |
| ↓ | Instructor helps develop elements of argument | |
| ↓ | Instructor critiques whiteboards | |
| IC | Instructor dictates claim, evidence and/or justification | |
| | **Argument Session** | |
| SC | Instructor monitors small group presentations with guiding questions. | |
| IC | Instructor monitors small group presentations with critique. | |
| IC | Instructor offers most of the critique - overshadowing students | |
| SC | Instructor gives time for post-argumentation discussion and potential claim change | |
| | **Reflective Discussion & Report Writing** | |
| | Instructor follows-up discussion after Argumentation Session | |
| | Instructor shares specific arguments with class and provides critique | |
| | Instructor reminds students of basic report tasks and requirements and sets due date | |

*Figure 8.* ADI-specific observation protocol (page 1 of 2) used to document facilitation techniques.

Course:______________________ Day/Time:____________________ Instructor:________________

| | | |
|---|---|---|
| | **Calibration of First Paper Peer Review** | |
| | Instructor asks guiding questions about general requirements for each section | |
| | Instructor addresses specific student concerns | |
| | Instructor provides detailed description of what should be included in each section of the report | |
| | **Group Peer Review** | |
| SC | Instructor lets students conduct peer review on their own for the rest of papers. | |
| | Instructor lets students conduct peer review on their own for all papers. | |
| | Instructor monitors task behavior | |
| IC | Instructor directs review progress and/or suggests specific review responses. | |
| | **Time Spent on Tasks** | |
| How long was the Argumentation Session? (~30 mins) | | |
| How long was the post-argumentation discussion? (~10 mins) | | |
| How much time was spent on the peer review? (45-60 mins) | | |

* SC: Student Centered
IC: Instructor Centered
All Criteria are not expected - Goal is towards SC

*Figure 9.* ADI-specific observation protocol (page 2 of 2) used to observe facilitation techniques.

## APPENDIX D: PRACTICAL EXAM ALIGNMENT WITH *EMPIRICAL* & *REPRESENTATIONAL* SCIENCE PRACTICES

Table 18

*Empirical science practices on the GC1 and GC2 practical exams*

| Science Practice | Description | GC1 | GC2 |
|---|---|---|---|
| Locate information relevant to a scientific problem. | Identify databases to search for information in the field relevant to a problem | What information are you given that identifies the product as copper(II) oxide (CuO)?<br><br>The combustion of the red powder requires another reactant. What is the chemical formula for the second reactant and what was the source of the second reactant? | Examine the data provided and use your understanding of chemical reactions, kinetics, and graphical analysis answer the guiding the question. Your argument should:<br>• Include a predicted rate law, with the correct k value and correct units for k.<br>• Include all the elements of a complete argument – claim, evidence and justification/reasoning. |
| Design an experiment to test a scientific question. | Develop a study that identifies relevant factors, and collects data to effectively examine the problem. | Describe in detail the procedure you will use to determine the concentration of the NaOH solution. Include details on preparing the burette, the analyte and conducting a titration. | In order to determine the molar concentration of the food dye solution from absorbance measurements, it is necessary to establish a Beer's law calibration curve. Describe in detail the experimental procedure you will use to prepare the calibration curve for your food dye solution. |
| Apply (or know when to apply) appropriate analytical methods to examine a scientific problem. | Identify and use (or know when to use) the "best" practices of the field (i.e. techniques/instrumentation). Execution of these skills. | **Observation Rubric:**<br>Burette prep/use - rinse with NaOH, remove funnel, remove air bubbles, reading correctly<br>Shade of pink<br><br>Use of Balance - tared balance, close doors, clean spills, don't return solid to container, return lid<br>KHP Solution - transfer to flask, dissolve in water | **Observation Rubric:**<br>Use of pipette - no liquid in bulb; use index finger and not switch hands; no bubbles when drawing liquid.<br><br>Prepare a serial dilution. |
| Appraise an experiment design to identify elements and limitations and how they impact scientific findings/conclusions | Identify strengths and weaknesses of research design elements (e.g., potential sources of error, variables, experimental controls). | | Include a discussion and possible explanation for the observed variation in group data. |
| Troubleshoot technical issues | Evaluate a scientific problem to identify possible technical causes | Proper use of Burette, balance and glassware | Proper use of pipette, colorimeter and glassware |

Table 18 continued

*Empirical science practices on the GC1 and GC2 practical exams*

| Science Practice | Description | GC1 | GC2 |
|---|---|---|---|
| Evaluate evidence and critique experimental designs | Understand the limits of correlational data and experimental design elements | | Include a discussion and possible explanation for the observed variation in group data. |
| Interpret basic statistics – averages, SD. | Understand the need of basic statistics to quantify uncertainty in data or draw conclusions | | Conduct linear regression.<br>Interpret best fit from r-squared values |

Table 19

*Representational science practices on the GC1 and GC2 practical exams*

| Science Practice | Description | GC1 | GC2 |
|---|---|---|---|
| Generate a hypothesis or make a prediction based on a scientific model. | Identify an appropriate scientific model and apply it to the given problem in developing a hypothesis or making a prediction. | Using your answers to questions 2 and 3 write a balanced chemical equation that represents what happened when the red powder was heated if it was copper metal or copper(I) oxide. | |
| Construct an argument based on evidence. | Make a claim that answers a question or provides a solution to a problem. Support the claim with evidence and justify why the evidence is appropriate. | Based on your theoretical yield and the actual yield given in question 1, what is your claim for the hypothesis – The red powder is copper metal?<br><br>Write an argument using your data as evidence and provide a justification for the evidence used. | What do the evaporation rates indicate about the relative strength of the intermolecular forces present in the two liquids?<br><br>Using the cation flow chart provided and the qualitative results described below, identify what cation(s) were and were not present in the sample. Justify your claim.<br><br>Write an argument answering the question: What is the rate law for the metabolism of aspirin? |
| Represent data in a visual form. | Convert relevant information into an appropriate visual representation given the type of data. | | Prepare a graph, conduct linear regression |
| Construct a data table | Labels for dependent and independent variables, replicates, units, sig. figs. | Use this area to create a data table and record your data. | Use this area to create a data table and record your data. |

Table 19 continued

*Representational science practices on the GC1 and GC2 practical exams*

| Science Practice | Description | GC1 | GC2 |
|---|---|---|---|
| Data analysis | Apply disciplinary knowledge to data analysis, i.e. calculations. | Sample Molarity Calculation. Show your set-up with the correct units and significant figures. What is the molarity of your unknown base?<br><br>Based on your balanced equation for Hypothesis 1 and the amount of red powders used in Trial 1, calculate how many grams of copper(II) oxide (CuO) should have been produced, i.e. theoretical yield. Show your work.<br><br>Examine the data provided given on the student notebook page. Complete the table below, Show your work. | Use the equation for the line of best fit to calculate the molarity of the sample of food dye that will be exported to Canada. |

Table 20

*Empirical science practices on the GP1 and GP2 practical exams*

| Science Practices | Description | GP1 | GP2 |
|---|---|---|---|
| Design an experiment to test a scientific question. | Develop a study that identifies relevant factors, and collects data to effectively examine the problem. | Describe in detail the experimental methods that you will use to measure the hanging mass M, and the rotational period T. | Describe in detail the experimental methods that you will use to measure current through the unknown circuit element *I*, voltage across the unknown circuit element *V*, and how you will determine the resistance given this data.<br><br>Make a plot of I vs. V in such a way that you can determine if the unknown circuit element is a resistor. |
| Apply (or know when to apply) appropriate analytical methods to examine a scientific problem. | Identify and use (or know when to use) the "best" practices of the field (i.e. techniques/instrumentation). Execution of these skills. | Describe in detail the experimental methods that you will use to measure the hanging mass M, and the rotational period T. | Describe in detail the experimental methods that you will use to measure current through the unknown circuit element *I*, voltage across the unknown circuit element *V*, and how you will determine the resistance given this data. |
| Appraise an experiment design to identify elements and limitations and how they impact scientific findings/conclusions | Identify strengths and weaknesses of research design elements (e.g., potential sources of error, variables, experimental controls). | Describe in detail the experimental methods that you will use to measure the hanging mass M, and the rotational period T. | Describe in detail the experimental methods that you will use to measure current through the unknown circuit element *I*, voltage across the unknown circuit element *V*, and how you will determine the resistance given this data. |
| Troubleshoot technical issues | Evaluate a scientific problem to identify possible technical causes | | Describe in detail the experimental methods that you will use to measure current through the unknown circuit element *I*, voltage across the unknown circuit element *V*, and how you will determine the resistance given this data. |
| Interpret basic statistics – averages, SD. | Understand the need of basic statistics to quantify uncertainty in data or draw conclusions | Describe in detail the experimental methods that you will use to measure the hanging mass M, and the rotational period T. | Make a plot of *I* vs. *V* in such a way that you can determine if the unknown circuit element is a resistor. |

Table 21

*Representational science practices on the GP1 and GP2 practical exams*

| Science Practices | Description | GP1 | GP2 |
|---|---|---|---|
| Construct an argument based on evidence. | Make a claim that answers a question or provides a solution to a problem. Support the claim with evidence and justify why the evidence is appropriate. | Based on your measurements, make a claim about the relationship between period and hanging mass for this circular motion.<br><br>Write an argument/conclusion using your data as evidence to support your claim. | Based on your measurements, make a claim about whether the unknown circuit element is a resistor or not.<br><br>Write an argument/conclusion using your data to support your claim with evidence and provide a justification for the evidence used. If you conclude that the unknown circuit element is a resistor, give the value for the resistance as part of this evidence. |
| Integrate and apply knowledge across sub-disciplines. | Identify and use concepts from previous courses to interpret given data and observations. | Write an argument/conclusion using your data as evidence to support your claim. | Write an argument/conclusion using your data to support your claim with evidence and provide a justification for the evidence used. If you conclude that the unknown circuit element is a resistor, give the value for the resistance as part of this evidence. |
| Represent data in a visual form. | Convert relevant information into an appropriate visual representation given the type of data. | Show a plot of $T$ vs. $M$ that best supports the claim you just made. | Make a plot of $I$ vs. $V$ in such a way that you can determine if the unknown circuit element is a resistor. |
| Interpret visual representations of data. | Interpret or explain information presented in visual forms. | Make a plot of T vs. M in such a way that you can determine a relationship between period and hanging mass.<br><br>Write an argument/conclusion using your data as evidence to support your claim. | Make a plot of $I$ vs. $V$ in such a way that you can determine if the unknown circuit element is a resistor.<br><br>Write an argument/conclusion using your data to support your claim with evidence and provide a justification for the evidence used. If you conclude that the unknown circuit element is a resistor, give the value for the resistance as part of this evidence. |
| Construct a Data table | Labels for dependent and independent variables, replicates, units, sig. figs. | Use this area to create a data table and record your data. Include a data table in your report. | Create a data table to record your data. Include it in your report. |
| Data Analysis | Apply disciplinary knowledge to data analysis, i.e. calculations. | Write an argument/conclusion using your data as evidence to support your claim. | Write an argument/conclusion using your data to support your claim with evidence and provide a justification for the evidence used. If you conclude that the unknown circuit element is a resistor, give the value for the resistance as part of this evidence. |