Graduate teaching assistant fidelity of implementation in introductory physics laboratories

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This study reports the fidelity of implementation by Graduate Teaching Assistants (GTAs) of the Argument-Driven Inquiry (ADI) instructional model in introductory physics laboratories. An ADI specific observation protocol was used to document the facilitation techniques of two GTAs during three investigations of a semester long course. This observation protocol considers each aspect of the ADI instructional model and therefore reveals fidelity of implementation. GTAs in general physics I laboratories were observed during the first semester of course wide implementation. The observation protocol revealed a difference in facilitation techniques between the GTAs. There was also a significant difference for the median scores on the end-of-course practical between the two sections observed.

I. INTRODUCTION

It is assumed that laboratory instruction reinforces the content from lecture, without evidence indicating that this is the case [1]. For this reason, many of the experiments in a traditional laboratory setting instructed students on what to do and not necessarily why they were doing the task. This has led to students going through the motions of the experiments without having a deep connection with the subject matter [2]. An issue with the traditional laboratory curriculum is that students are not taught how to approach experiments scientifically [3]. Traditional laboratories do not guide students through the science practices used by physicists [3]. In addition, majority of students are now taking introductory physics courses as prerequisites for other disciplines. This has prompted a need for the laboratory portion of disciplinary science courses to evolve in order to engage students in authentic science practices and transferable skills which prepare students for a wide range of careers [1].

The Cross-Disciplinary Practice Focused Undergraduate Laboratory Transformation (X-Labs) Project was designed to transform the introductory laboratories in chemistry, biology and physics at East Carolina University (ECU). These reformed laboratories use similar language across the introductory courses in all three disciplines to introduce and reinforce important science practices. This will allow for positive transitions into upper-division laboratory courses or into undergraduate research. The Argument-Driven Inquiry (ADI) instructional model was the foundation for reform of the introductory laboratories for chemistry, biology and physics at East Carolina University (ECU).

The majority of introductory laboratories are facilitated by graduate teaching assistants (GTAs). Research has determined that due to teaching being a secondary emphasis of GTAs, there is little focus on the development of this skill [4]. GTAs are typically assigned to teach as soon as they become graduate students; often with little or no training [5]. If measurable goals are in place it will be possible to determine if the GTAs are facilitating their sections effectively [6]. In this study, GTAs from two different sections of general physics I laboratory were observed to determine their fidelity of implementation and impact on student assessments.

II. THEORETICAL FRAMEWORK

The introductory laboratories and the associated lab practicals for the X-Labs project were designed to have students participate in science practices as defined by *Next Generation Science Standards* (NGSS) [3, 7]. The laboratories were set up in this manner so that students would learn how to think and behave like scientists [8, 9]. These science practices, as outlined in Table I, are broken down into two categories: *empirical* and *representative* science practices [10]. According to Ford, scientists explore the natural world with *empirical* science practices by planning and carry out an investigation, followed by analyzing and interpreting data. Scientists describe the natural world to peers and the community with *representational* science practices [11], such as constructing an explanation, arguing from evidence, sharing findings, and evaluation and critique. The alignment of these science practices in traditional and in ADI laboratories is represented in Table I. Students are given more opportunities to participate in *representative* science practices in the ADI model than in the traditional laboratory model.

TABLE I. Alignment of science practices with laboratory format.

Science Practice	Traditional	ADI
Empirical		
Plan investigation	No	Yes
Perform Investigation	Yes	Yes
Analyze/Interpret Data	Yes	Yes
Representative		
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 in each investigation through collaboration in small groups which encourages the development of science practices. The ADI instructional model engages students in authentic science practices through investigation design, data collection and analysis, argumentation, writing, peer-review, and revision. There is a robust body of research that supports the use of the ADI instructional model to improve student learning outcomes on a range of activities including on practice focused exams, science writing and argumentation [10, 12-16].

III. STUDY CONTEXT

Each investigation takes place over a three-week period. Students perform the pre-lab during the first week, followed by the investigation in the second week, the students then participate in an argumentation session the third week, and the peer review is completed online through Peergrade [17]. The students in each section are provided videos that were recorded by an instructor on writing a lab report and performing a peer review. Each section of introductory physics laboratories are facilitated by a Graduate Teaching Assistant (GTA) that guides the students through four investigations.

GTA roles in a traditional laboratory typically line up with *instructor-centered* techniques, however in the ADI instructional model the GTAs are expected to provide *student-centered* facilitation techniques [15]. In an *instructor-centered* classroom, the students are lectured at and/or provided answers to their questions, whereas in a *student-centered* classroom, students are allowed to explore scientific phenomena and are asked guiding questions that allow them to build on their pre-existing knowledge. The GTAs that are in charge of traditional laboratories tend to provide *instructor-centered* facilitation techniques, whereas, in the ADI instructional model the GTAs are expected to provide *student-centered* facilitation techniques.

All work was conducted in introductory physics laboratories at ECU, a primarily undergraduate institution, during the fall semester of 2018 which lasted 16 weeks. The general physics laboratory I students are often enrolled in either algebra-based or calculus-based lecture course simultaneously with the laboratory course.

Students enrolled in the laboratory section have diverse majors and take this course to satisfy a portion of their natural science general education credit. The laboratory portion meets weekly for two hours During the Fall 2018 semester, the ADI instructional model was fulling implemented in 26 sections. There were 523 students enrolled in these sections, with a maximum laboratory size of 22 that were taught by a GTA.

GTAs facilitating two sections of general physics I laboratories were the participants of this study. The GTAs were selected from individuals that participated in the summer training on the facilitation of the ADI instructional model. 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 physics, followed by weekly meetings throughout the semester. During the combined training, the GTAs were split into groups 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 that helped students work in groups. The training was structured this way to introduce the GTAs new to the ADI instructional model to desired techniques for facilitation.

Each GTA in the physics department, typically facilitates three sections of laboratory that are assigned to them according to their availability. Each section was led by the instruction of one GTA. The GTA in each section was observed by a non-participating observer during the semester of full implementation of the ADI instructional model.

During the Fall 2018 semester, this university for eight days due to a natural disaster during investigation 1, which led to 2-weeks of general physics I laboratory being cancelled over the period of the semester. This required adaptation of the course and one of the investigations was not completed during this semester.

IV. METHODS

This mixed method study addressed how GTAs implementation of ADI impacts student performance in order to answer the research question: *How does graduate teaching assistant implementation of Argument-Driven Inquiry impact student performance on an end-of-course lab practical in introductory physics?* The instruments used to answer this question were an ADI specific observation protocol, the students' first lab report, and the lab practical. Each of these instruments has been described in the following sections.

A. Observation protocol

Instructors in general chemistry I and general chemistry II laboratories were observed for the 3-week investigation in order to create a continuous observation protocol that would consider each stage of a complete ADI investigation. Continuous protocols, collect information about behaviors that occur throughout the whole laboratory. 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 for the researcher to document the observed behaviors. The observer puts a mark in the appropriate box once a facilitation technique is observed. The observation protocol has at least one option for *student-centered*, median, and *instructor-centered* tasks for each section of the ADI instructional model (e.g. developing a proposal). A task is considered median if it lies somewhere between *student*-centered and *instructor-centered.* The observation protocol also has a place to document the amount of time allowed for the argumentation session and the post-argumentation discussion.

During summer of 2018, the observation protocol was used to observe four instructors facilitating general chemistry sections in order to validate the observation protocol and determine if the instrument's design revealed the fidelity of implementation. Once the observation protocol was validated for general chemistry laboratories using the ADI instructional model, it was implemented in general biology laboratories and general physics laboratories by different members of the research team. These members compared the results from their observations to determine if the instrument was reliable across disciplines for the general laboratories in the X-Labs project. The instrument revealed similar results across disciplines.

Two GTAs were observed to determine the range of student-centered to instructor-centered techniques employed. 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. 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.

B. Lab reports

During each investigation, the students are required to write a 2-page lab report that is broken down into three sections. The first and second section are ½-page and the third section is a full-page. Students each discuss the science concept, guiding question, and how they are related in the first section. The second section gives a brief description of how the group performed the investigation and any methods that were used to reduce error. In the final section, the students answer the guiding question with justification using their evidence and the science concept, compare their information with other groups, and discuss any limitations. The lab reports are graded with a standard rubric.

C. Lab practicals

The lab practicals for the general physics laboratories were designed to measure both *empirical* and *representative* science practices. The lab practical had questions that required the students to design an experiment, collect and analyze data, make a claim, and write a scientific argument. The students were provided a set of masses, a plastic tube, and a stopper that is connected to a string that slides freely through the tube. The students had to design and perform an investigation in order to determine the relationship between a hanging mass (M) and period (T). The lab practical was developed and validated to assess both *empirical* and *representative* science practices [18].

In this study, the students' 1st lab reports and the lab practical results were used to assess student performance. The grading methods by both GTAs were validated by an individual from the research team to determine that the rubric had been used correctly. During this process, it was discovered that one of the GTAs for introductory physics I had not used the standard rubric for either the lab report or the lab practical. The 1st lab reports and the lab practicals for this section were regraded by a member of the research team in order to get a true representation of the students' grades. A second member of the research team graded 25% of the lab practicals for this section with the standard rubric to validate the scoring and inter-rater reliability was established between the two graders.

V. RESULTS/DISCUSSION

The differences in facilitation techniques observed can be seen in Fig. 1 (GTA-a) and Fig. 2 (GTA-b). The largest variance was during the argumentation session, data collection, and developing a proposal. GTA-a had never taught a section of laboratory with the ADI instructional model, whereas, GTA-b had assisted with the pilot section in a previous semester. Exemplars of the facilitation techniques by the GTAs for the developing a proposal, data collection, and argumentation session of the 1D motion laboratory are located in Table II. These results indicate that the more experience a GTA has with the ADI instructional model, the more likely they will provide *student-centered* techniques, when GTAs ask questions during the argumentation session students tend to become passive learners and let the GTA dictate the conversation. The students in GTA-a's section were directed on what they should do for each of these stages, whereas GTA-b guided the students through the investigation.

Comparison of the medians on the 1st lab report is presented in Fig. 3. The median of the students from GTA-a's section was 57.85 compared to the median for GTA-b's section of 48.26. This indicates that the students in both sections are capable of writing the required lab report at the beginning of the semester. A Mann-Whitney *U* test was conducted to evaluate the hypothesis that the medians and the distributions of the lab reports were the same across both GTAs. The results of the test indicated that there was a significant difference, $p < 0.05$.

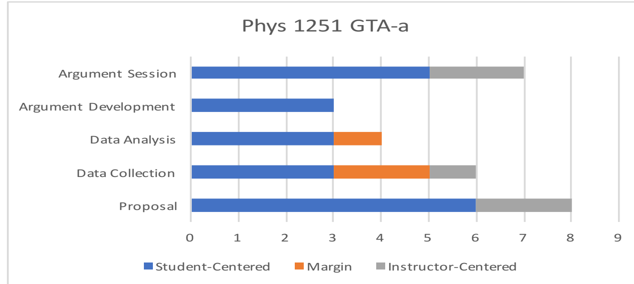

Fig. 1. (Color online) Facilitation techniques demonstrated by GTA-a for general physics I laboratory.

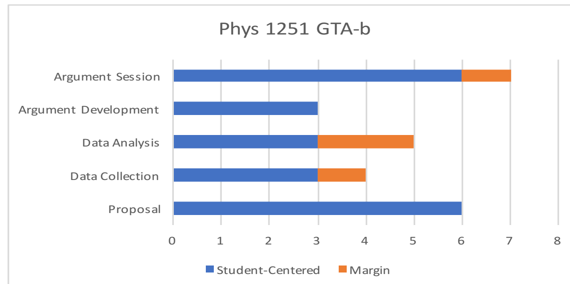

Fig. 2. (Color online) Facilitation techniques demonstrated by GTA-b for general physics I laboratory.

TABLE II. Comparison of facilitation techniques used by GTAs during an investigation about 1D motion of a fan cart.

Stage/GTA	Behavior
Proposal	
GTA-a	GTA told students to document what fan setting and how many weights they used.
GTA-b	GTA asked students what they were measuring when an issue was spotted with the proposal.
Data Collection	
GTA-a	GTA was disengaged, unavailable to the students, and was working on homework for another class.
GTA-b	GTA was observing the groups from the front of the room and was available if the students needed assistance.
Argumentation Session	
GTA-a	GTA asked the presenter about their data (acceleration & mass) and then stated that they analyzed the data wrong. 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.
GTA-b	GTA mentioned how quiet the room was and then prompted the travelers to find errors on the whiteboard and have the presenter fix them. 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.

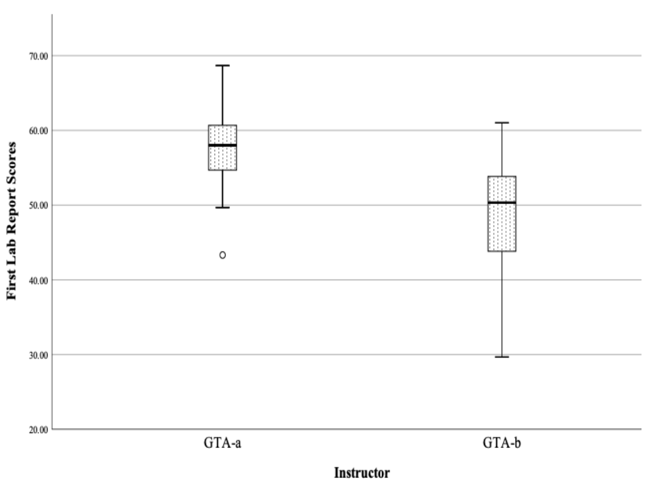

Fig. 3. Comparison of scores for the first lab report.

A Mann-Whitney *U* test was conducted to evaluate the hypothesis that the medians and the distributions of the lab practicals were the same across both GTAs. The results of the test indicated that there was a significant difference, $p < 0.05$. Students in GTA-b's section had an average grade of 83.15, while students in GTA's section average grade of 73.32. Figure 4 shows the distributions of the scores for the two sections.

Students in GTA-b's section performed better on the lab practical than did the students in GTA-a's section even though the opposite was true for the 1st lab report. There were more students in GTA-a's section that failed the lab practical and only two students scored 90 or higher, and two students failed the lab practical with a score below 60%. Five students received a score of 90 or greater. Only one student failed the lab practical in GTA-b's section and that was due to the student not including a table in their argument. Upon examination of the rubrics, all of the students in GTA-a's section assumed the mass on the weights were correct, whereas, students in GTA-b's section used a balance to determine the mass of the weights.

VI. IMPLICATIONS

The observation protocol that was developed for this study can be used during the semester to determine if the GTA is providing the desired techniques and indicate when training might be needed to produce these techniques. The best results for students enrolled in an ADI instructional model course happen when the GTAs facilitate techniques that are more *student-centered* than *instructor-centered*. When GTA's do not demonstrate fidelity of implementation for this method, it may negatively impact the students' performance on the end-of-course practical.

GTA-a demonstrated *instructor-centered* techniques during the semester while the students developed their proposal and collected data, the students in this section underperformed the students in GTA-b's section during this portion of the practical. This indicates that asking students guiding questions during the semester when there is a flaw in their investigation could lead to better performance on the end-of-course practical.

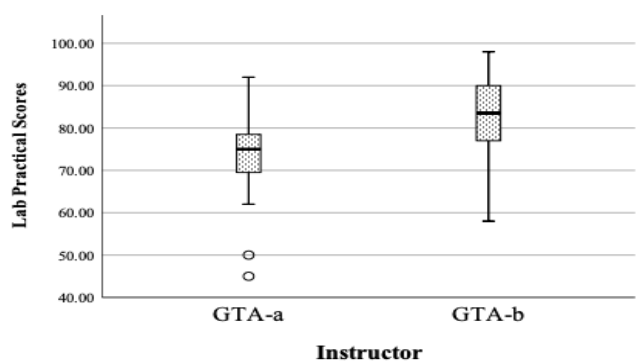

Fig. 4. Comparison of lab practical scores by graduate teaching assistant.

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