Learning assistants’ teaching strategies for promoting scientific inquiry among undergraduate students in a physics laboratory setting

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Introductory labs in STEM courses are often designed with the goal of promoting scientific reasoning among students. Instructors play a role in reaching this goal, and the pedagogical practices instructors adopt can support or inhibit the development of student scientific reasoning. In particular, novice instructors who are still grappling with lab epistemology may enact a range of teaching practices, some of which may not be helpful in reaching the goals of lab instruction. We present findings from a study of 58 first-time undergraduate Learning Assistants (LAs) presented with a teaching scenario from an introductory physics lab. In our analysis, we identify teaching strategies used by LAs to support the scientific reasoning of their students and barriers or alternate approaches that prevent LAs from successfully providing this support. We find that a common barrier to LA support of student scientific inquiry is LAs’ preconceived notions of a "correct answer" to the lab task that students must reach, which causes these LAs to shift to strategies more in line with conducting validation experiments.
**I. INTRODUCTION**

Physics labs have been the subject of substantial research and reform in physics education. Pedagogically, many lab reforms have aimed to make the practices that occur in physics labs mirror the disciplinary practices of physics in an effort to promote student scientific thinking and lab skills [1–4]. In moving toward the goal of creating labs that meaningfully impact student scientific thinking, two critical features have emerged from research: labs must allow students to participate in decision-making and do away entirely with goals that ask students to verify established theories [5]. The latter of these two features can be challenging to implement, since many students believe the aim of introductory labs is the verification of physics theory [6, 7], and will readily shift toward framing labs as validation experiments if given any sort of cue or hint to do so [8].

Reformed labs have benefited from increased instructional support in the form of additional instructors present to assist students. One potential source of additional instructional support has been near-peer instructional programs. The Learning Assistant Program is one such model for near-peer instruction in which undergraduate students — often former students of the course in question — act as co-instructors in a course [9]. The presence of undergraduate Learning Assistants (LAs) in physics learning environments has been connected to lower failure rates [10–12] and gains on physics concept inventories among students [13–15]. A central tenet of the Learning Assistant model of near-peer instruction is that LAs are exposed to discipline-based pedagogy and research through a pedagogy course in which every first-time LA must enroll [9]. Studies of LA pedagogical knowledge development have shown that LAs more readily take up some pedagogical ideas than others [16]. Beyond any formal training they may receive, LAs also bring in numerous ideas about what teaching and learning should look like as they navigate the boundary space of being both students and teachers [17].

Compared to research on the practices and outcomes of LA programs in discussion and recitation sections, the results of their implementation in physics labs have been underreported, though LA programs have been successfully implemented and studied in lab settings within other STEM disciplines [18–20]. Lab instruction and pedagogy can be messy — students often hold conflicting and seemingly contradictory epistemological beliefs that differ from the beliefs of their instructors about the purpose of labs [6, 7]. LAs, being experienced students but relatively new teachers, are likely to carry some of these conflicting beliefs as they draw upon their own experiences in their teaching, even when a “preferred” pedagogical approach is presented as part of the pedagogy course and weekly lab preparation meetings.

We seek to study the pedagogical practices of LAs in introductory physics labs and how they align or misalign with the goal of helping their students develop scientific reasoning skills. To this end, we have analyzed 58 first-time physics lab LA responses to a teaching scenario presented as a free response question in the LA pedagogy course. In our study, we have considered the following two research questions:

1. What pedagogical practices do LAs take up that support student scientific reasoning?
2. What barriers keep LAs from taking up such practices?

**II. METHODS**

In our analysis, we used an inductive coding approach to identify and code themes within a set of LA written responses [21]. Our coding approach focused on how LAs centered data or physics concepts in their responses, and statements LAs made about their hypothetical teaching moves. A second iteration expanded the scheme to codify specific teaching moves, as well as whether LAs indicated within their explanation whether they believe the task presented in the scenario had a single correct answer.

**A. Study Context**

The data for this study were taken from a free response question posed to LAs as part of the LA pedagogy course in the Fall 2022 and Spring 2023 semesters at a large Midwestern university. All the scenario responses were from first-time LAs. The pedagogy course included LAs from both introductory mechanics and introductory electricity and magnetism lab courses. Each semester, LAs are recruited from former students of the course — a noteworthy detail, as it means that each LA has previously been a student in the course in which they instruct, often as recently as one semester before. In the first weeks of the pedagogy course, LAs are presented with concepts such as open and closed questioning and science talk moves [24] to help them establish a baseline set of strategies for instruction.

In our context of study, students in the labs use the Interactive Online Laboratory tool (IOLab) to complete laboratory tasks. The IOLab system includes a multi-sensor measurement device and data analysis software that receives and displays data from the device [22]. In labs, the students are given ill-structured tasks designed to encourage sense-making and build adaptive expertise [3, 23]. These lab sections are generally staffed by one graduate teaching assistant and 1–2 undergraduate LAs.

We identified this set of responses for analysis due to its richness and variety, and the emergence of two divergent themes with respect to LAs’ lab instructional approaches. When presented with a hypothetical teaching scenario from one of the labs, some LAs focused on encouraging students to use the data to make a claim, while others prompted students to think about physics concepts to make sense of the data. We also saw LAs reference a range of teaching moves. Some LAs specifically called out their use of the strategies from the pedagogy course, while others cited different teaching strategies they had learned through their own experiences.
B. The Scenario

In the prompt, LAs were presented with a scenario situated within a lab assignment from their introductory mechanics course, in which students were asked to measure the acceleration of their IOLab device as it rolled up and down a ramp. Students were asked to test the claim that "the IOLab’s acceleration on the ramp is the same on the way up as it is on the way down." In the scenario, LAs were told that four students were arguing over the results of their data, with two students claiming the accelerations were the same while two other students claimed the up-acceleration was larger than the down-acceleration. The scenario ended by asking the LA how they would respond, with a final clarifying statement that their response would be graded on completion and not on any assessment of the correctness of their answer.

In the actual lab activity the scenario replicated, students performing the lab could either accept or reject the claim that the accelerations were the same depending on their data. For some experimental setups, the friction in the wheel bearing could be sufficient to make the accelerations differ when compared via a statistical t’ calculation [25]. For other setups, the error analysis may not be able to conclusively show any difference between the accelerations. The goal of the activity was therefore not that students arrive at a "correct" answer, but that students make a claim grounded in their data.

In our coding, we aimed to deduce each LA’s perception of whether or not there exists a "correct answer" to the students’ problem within the scenario, as a glimpse into each LA’s epistemological views about labs. Since the LAs were prior students of the course, each of them had performed the lab activity described in the scenario, and may have recalled the answer they obtained when they did the experiment, or generated ideas about what they thought the correct answer should have been by considering physics principles. Ideally, LAs should not pick a side, but should instead encourage students to make their conclusions based on data, rather than based on what the LA or students expect to happen.

C. Analysis

The responses were first read individually by the authors and loosely coded for statements in which the LA focused the students’ attention on either relevant physics concepts or on the data the students had taken. After this first open round of coding, we discussed themes noted in each response, and devised a set of codes to capture how LAs used appeals to data and to physics concepts in their response — ultimately referred to as "pathways" with responses coded as data-driven, theory-confirming, or neither. We later refined the coding scheme to include a new set of codes for the types of teaching moves LAs alluded to within their responses. Based on our emerging sense that LAs’ epistemology could underlie their instructional approaches, we added codes for if the LA’s response made any mention of whether the lab the students were working on had one correct answer. As the codes representing epistemology were binary and constrained to each LA’s singular response in time, they served as a means of linking each LA’s personal understanding of the supposed outcome of this specific lab to their instructional approach.

At each step of coding, two independent coders worked together to generate codes for the first 20 responses to establish agreement, then coded the remaining 38 responses separately to allow for the calculation of inter-rater reliability (IRR). In each case, IRR was calculated using Krippendorff’s α [26]. For the pathways, IRR was α = 0.961. For the coding of whether or not the LA believed the lab task possessed a single correct answer, IRR was α = 0.801.

III. RESULTS

In this study, LAs took one of three pathways to addressing the lab scenario outlined in the prompt: (A) Guiding students to focus on and/or discuss their data within their group, then asking them to consider valid scientific interpretations of these results (classed "data-driven"; n = 22); (B) Guiding students to focus on the physics disciplinary content underlying the scenario and use it as a lens for considering the validity of their data (classed "theory-confirming"; n = 15); and (C) Avoiding mention of specific guidance, instead focusing on supporting better communication among group members in their response (classed "null"; n = 21). Our analysis seeks to unpack the pedagogical strategies LAs implement in guiding students through the inquiry process in a manner consistent with the scientific process, while considering what epistemological factors or teaching beliefs may underlie LA decisions to take an alternate path.

A. Teaching Moves Associated with Data-Driven Inquiry

In addressing research question 1, we identify some teaching moves associated with the pathway aligned with an authentic experimental design process wherein data drives the conclusion (pathway "A", "data-driven"), counter to a pathway that seeks to bring data into alignment with a pre-established physics outcome (pathway "B", "theory-confirming").

Opening with direct instruction. The majority of LAs who took pathway "A" gave direct instruction or asked very direct, closed questions at the beginning of their response. For example, in the following response, the LA asked the students to calculate a statistical t’ and use this value as the basis for addressing the physics claim:

I would tell them to look back at the statistical methods provided. It is a tenet of science that what the results say do not depend on the one reading them. If there [sic] are all looking at the same data, if they use the t prime value they
should be able to judge whether it is slowing down on the way down or not.

Here, the LA valued a set procedure for determining whether the data set representing the cart’s acceleration up the ramp was statistically significantly different than the data set representing the cart’s acceleration down the ramp. In some cases, LAs taking pathway "A" interpreted student conflict as rooted in students’ inherent mistrust of the data.

I would first ask to see their IOLab data and ask them what their conclusions are based off the data. Then I would ask why there is a disagreement. After that, I would say if there is an assumption that your data is incorrect, then address possible errors and what you think the correct answer is.

Establishing student "trust" in the data. In five of the responses, all aligned with the data-driven pathway ("A"), LAs approached the challenge of student doubt by asking the students to take their experimental trials more carefully, as to improve student trust in the data to drive their eventual conclusions. For example, one LA writes:

If time permits, it might be useful to repeat the trials and see if this is an experimental error. If not, I would first ask them to review their data and see how consistent their result is. Else, it is totally okay to have different opinions. I would ask students to discuss the opposing opinions in their discussion session on their lab report and elaborate on the reasons backing up each claim.

This LA made two distinct moves to establish trust in the data. First, they suggested additional trials, to see if the results in a second set of trials would be consistent with the first. Second, the LA also deemed it appropriate for members of the group to disagree, and take sides in the lab write-up — a move that explicitly valued differing interpretations and reinforced that there was no single correct answer.

Another LA took a similar approach to dispelling student concerns about data, orienting the conversation around specific sources of experimental error:

I would ask them to look over the data that they have. Whether or not the measured acceleration of both the upwards and downwards time frames were the same or not, I would ask them if they think that there was any error that could cause the two accelerations to look different. Since the data will objectively show whether the accelerations are the same or not, I may ask whichever group that disagrees with the data why they think that the data is wrong. Then, if there’s enough time, I might suggest that they try a different setup that would circumvent the potential sources of error that they listed.

This LA focused on systematic error and asked the group to reflect explicitly on this to bolster their confidence in the result. This LA’s response is another example of allowing the experimental data to "speak" and allowing students to disagree with it only if they have a valid concern about the experimental design, data collection, or analysis. Potential student concerns about the data simply being "wrong" were addressed by giving students the opportunity to change their experimental setup and observe its effects on the data.

Establishing trust in the data was associated with a more closed start to the conversation, in which LAs did not elicit student ideas. This may be because LAs who allow the data to "speak" are concerned that, by opening up theoretical conversations about how the data fits within the physics schema developed through lecture early on, they may promote the sense that there is some "correct answer" to the lab, and sow doubt about any result that does not fit this answer.

Open-ended support of student conclusions. As noted, LAs taking pathway "A" tended to begin their responses with direct prompting of students that centered on evaluating data collection and analysis protocols, with little room for student extrapolation about what they "should" theoretically see in these results. However, the more narrow questioning approach LAs employed at the beginning of these pathway "A" encounters tended to give way to a more open and responsive approach than seen in answers from LAs taking pathway "B", who tended to provide more targeted support to encourage students to come to a specific, supposed answer. This is to say, LAs taking pathway "B" may have led with a more open-ended approach, but ended with a more targeted prompting style as students neared a conclusion. We posit that this difference in the pattern of teaching moves may be associated with epistemological beliefs of LAs taking either pathway, since 60% of the pathway "B" LAs indicated a belief that there was one correct answer to the lab prompt while only 23% of the pathway "A" LAs indicated this belief in their response.

B. LA Barriers to Supporting Scientific Inquiry in Open-Ended Labs

In addressing our second research question, we used sample responses from LAs taking pathway "B" or "C" to unpack barriers that may have prevented LAs from taking pathway "A". We found evidence of three barriers, but will address in this paper the most prevalent: LAs who carried into the lab with them a sense that there was one correct answer tended to take pathway "B", guiding students to use the data to confirm an expected result. That is to say, LAs who believed that there
was one correct answer that students ought to reach often pursued verification-seeking procedures in their responses.

TABLE I. Breakdown of LA responses based on pathway taken and belief that the lab task has a correct answer. (n = 58)

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Total responses</th>
<th>Believe in correct answer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Responses</td>
<td>Percent</td>
</tr>
<tr>
<td>A: Data-Driven</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>B: Theory-Confirming</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>C: Null</td>
<td>21</td>
<td>9</td>
</tr>
</tbody>
</table>

Across the 58 LA responses, 40% of responses (n = 23) showed evidence that the respondent believed there was one correct answer to the lab prompt. Table 1 shows the breakdown of LA responses by pathway and whether responses implied a belief in one correct answer. 60% of LAs who took a theory-confirming pathway ("B") revealed that they believed there was one correct answer to the lab prompt, while only 23% of LAs who took the data-driven pathway ("A") showed any sign of believing such a correct answer existed. A chi-square test performed between the data-driven and theory-confirming groups shows that LAs who took a data driven approach were less likely to believe in a correct answer to the lab task, $X^2(1, N = 37) = 5.268, p = .0217$.

LAs who took a neutral stance on the question of the "correct answer" tended to prime students to focus on their experimental design and data, and allow their data to inform their conclusion. An example of this approach appears in the following response, in which the LA said they would ask the disagreeing students to consider whether the answer to the lab prompt could depend on the way they initially chose to set up the experiment, such as the angle of the ramp:

*I would tell them to try the experiment with the ramp at multiple different angles and see if the difference between the up and down acceleration measured by the iOLab is consistent throughout all trials.*

Here, the LA guided the students to consider the impacts of an additional factor — the ramp’s angle — on the motion of the iOLab up and down the ramp by simply performing the experiment again after adjusting the ramp’s angle. In their response, the LA pushed the students further to consider that their result was not definitive, but rather could be a consequence of choices they made in the experimental design. Although the LA made no mention of the next possible step, their focus on data, and hint of a possible finding that there would be a discrepancy in the outcome based on the ramp’s angle, may set students up for a more robust physics reasoning discussion as they grapple with the results.

On the contrary, some LAs began by either guiding students to reason through a force analysis of the cart as it moves up and down the ramp, or directly explaining the physics of the situation to the students. These LAs tended to center the conversation around a correct final answer at which students "should" arrive.

*I would tell them to write out the free body diagram and to solve it first conceptually, then to use their measurements to support that claim. Once they drew the free body diagram, I would isolate the forces moving the iOLab in the +/- x direction. Then, after dividing by mass, we could look at just the accelerations. Then I would ask them to relate the accelerations going up and going down to each other. After that, once they realize that there is more acceleration on the way up, they can use this to relate to their measurements.*

Here, the LA centered physics to explain a desired result. It is not clear from the response what the LA planned to do if the student’s results fell outside of this expected outcome.

IV. CONCLUSIONS

The aim of our study is to begin to explore the ways in which the practices of LAs in introductory labs may differ from LAs who teach in other contexts (e.g. discussion, lecture, office hours, etc.). As lab reforms in physics continue, we expect the implementation of LA programs in labs to increase as a means of enacting and sustaining these reforms. The scope of the work presented in this manuscript is limited, but we hope that it can be used to inform further studies of the practices of LAs and other instructors teaching in lab settings.

While we have identified one barrier to novice instructors’ implementation of lab pedagogy, we acknowledge that many other barriers may exist. Our analysis showed limited evidence of other barriers. For example, many novice LAs have not yet developed the pedagogical skills to determine when to “hold back” information that students can discover for themselves. In other responses, it is evident that many LAs lack confidence in their ability to perform error analysis, or may not philosophically understand its value. These two additional barriers will be further explored in future work.

In thinking about the preparation and training of LAs for lab instruction, it may be helpful to consider the work that has been done in effectively training graduate teaching assistants in lab instruction [27]. We recommend anyone who utilizes LAs as instructors in lab settings to ensure that their LA pedagogy course specifically confronts the topics of supporting student reasoning and error analysis in order to help LAs refine their understanding of these topics beyond the ideas they may have learned during their own experiences as students.

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