Students' varying responses to instructor prompts for frame shifts in physics labs

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Research has shown that students in inquiry-based physics labs often expect their experiment to verify a known theory or model, contrary to the goals of the lab. It is important, therefore, to identify ways for instructors to shift students' expectations or *epistemic frames* to those in line with scientific inquiry. In this paper, we analyze video recordings of one inquiry-based lab session in which the instructor intentionally encourages students to *falsify*, or disprove, the claim under investigation. We find that students operationalize the instructor's prompt by taking up one of two distinct epistemic frames: *open outcome* and *verification*. Students in the open outcome frame initially expect to falsify their claim, but form other conclusions in the face of alternative evidence. Students in the verification frame, however, view falsification as verifying that a claim is false and do not consider other possible outcomes even when they find conflicting data. These results suggest that students may interpret instructor prompts for frame shifts in very different ways. We argue that to shift students to epistemic frames in line with scientific inquiry (e.g., the open outcome frame), instructor prompts should explicitly address uncertainty in outcomes (regarding an experimental result as unknown) and epistemic agency (perceiving oneself as a producer of knowledge).

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I. INTRODUCTION

In response to the call to engage students in the iterative process of science [1–4], many undergraduate physics labs have transitioned away from model-verifying activities and toward open-ended inquiry tasks [5–8]. Such inquiry-based labs promote *uncertainty of outcomes* by encouraging students to draw conclusions supported by their data, regardless of what outcome they expect based on canonical models [9]. They also foster *epistemic agency* by giving students authority over the knowledge they construct with their experiments [10–13]. Students in these labs, however, often expect that lab experiments have a predetermined outcome and do not perceive themselves as having control over the knowledge formed from experimental data [14, 15]. The way that many students *epistemically frame* labs, therefore, is not in line with the instructional goals.

Framing refers to an individual's stable set of expectations in a particular context or how they would answer the question "what is it that's going on here?" [16–18]. Epistemic framing, specifically, is an individual's expectations related to the kinds of knowledge they are to construct and how they will construct it [19]. The limited research on students' epistemic frames in inquiry-based labs has shown that students often hold a *confirmation* frame, expecting to validate a known theory or model in physics [14, 15, 20–24]. Though this frame may lead to productive lab behaviors, such as sense-making in some instances [25], it often leads students to engage in *questionable research practices* [14]. Such practices include manipulating uncertainty values and hedging conclusions toward the confirmatory result. In this paper, we define a similar, but broader, *verification* frame where students have an experimental outcome in mind and want to prove it. This expected outcome might be from their physics textbook (the confirmation frame), what they think the instructor wants them to find, or something else. The verification frame is problematic for the same reasons as the confirmation frame.

It is important, therefore, to identify ways for instructors to shift students' frames to those in line with scientific inquiry [1–4]. Though previous work has shown that instructors can prompt frame shifts in physics problem solving contexts [26–28], the relationship between instructor and student framing in physics labs is understudied. In the current analysis, we examine a lab instructor's attempt to shift students' frames by prompting *falsification*. Falsification refers to science philosopher Karl Popper's argument that scientific ideas should be refutable [29, 30]. Thus, this instructor encouraged students to design experiments capable of disproving the claim under investigation.

We analyzed video recordings of one of this instructor's lab sessions to address the following research question: How do students operationalize the instructor's prompt for falsification? We find that multiple lab groups attempt to take up falsification, but they do so in two very different ways. Some groups take up an *open outcome* frame where they are open to drawing any conclusions supported by their data. In contrast, other groups take up the verification frame, trying to verify that their claim is false in order to satisfy what they think the instructor meant by falsification. These results suggest that students engaging in the same activity and receiving the same instructor prompt may take up very different epistemic frames. We will argue that the key differences between these frames are students' sense of uncertainty of outcomes and enactment of epistemic agency. We will also conjecture how the instructor's framing led to each group's behaviors.

II. METHODS

A. Instructional context

The data come from one lab section of an introductory mechanics course for engineering and other science majors at Cornell University. This section contained 19 students, 11 of whom identified as men and eight of whom identified as women. Most students were White or Asian/Asian American and the majority were first- or second-year students. The teaching assistant (TA) for this session was a graduate student familiar with physics education research (the TA's demographic information is masked to preserve anonymity).

We collected video and audio recordings of this lab section because word choice and gestures allow us to infer individuals' framing [31–33]. All students and the instructor consented to participate in video research. We focused our analysis on the first lab of the semester, when students are more likely to hold a verification frame. This lab spans two sessions and prompts students to evaluate the amplitude dependence of the period of a pendulum [5]. During the first session, students identify and reduce sources of uncertainty in their period measurements. In the second session, students compare the period of the pendulum from 10° and 20°. Students are provided a statistic called *t-prime* (t') [5], analogous to a Student's t-test, to determine whether their two data sets are distinguishable according to the following interpretations:

- $t' < 1$: the data sets are indistinguishable
- $1 < t' < 3$: inconclusive
- $t' > 3$: the data sets are distinguishable.

About halfway through the second session, the TA announces that one group performed precise enough measurements to find a difference in the period from the two amplitudes. The TA commends this group, mentioning to the class, "*If you are not confident of the extent to which there is an angular dependence, you should probably talk to a group that is confident*." The TA then prompts a mechanism testing activity (1 h long) in which students test whether a specific mechanism, such as tension in the pendulum string, explains the observed amplitude dependence. When introducing the activity, the TA proclaims, "*The only way to investigate something is to try to prove it wrong, so as you design your experiment, you should not try to prove why the one you picked is the right one, you should be attempting to falsify it*." The TA, therefore, explicitly confronts the confirmation frame and instead encourages students to design experiments that can disprove the claim that their assigned mechanism is the one responsible for the observed amplitude dependence.

B. Video analysis

Because of the TA's direct attempt to shift students' frames, we focused our analysis on the mechanism testing activity. Five out of seven groups (two to three students per group) in the section verbalize an expectation to falsify their mechanism – they try to operationalize the TA's prompt. The first and second authors fully transcribed the video of each of these groups and then coded evidence of students' epistemic framing using criteria similar to that in Ref. [15]. This evidence included all speech and behaviors related to students' expectations for the experimental result: discussions about the expected result itself, reactions to experimental data or statistical analysis based on these expectations, and negotiations of the conclusions to be drawn from their experiment.

The first and second authors brought video episodes of moments coded as evidence of epistemic framing to discuss among a larger research team. In these discussions, we interpreted and compared the groups' speech and behaviors. We identified and characterized two epistemic frames that lab groups took up: open outcome and verification. Groups in the open outcome frame expected to falsify their mechanism, but formed other conclusions when faced with alternative evidence. In contrast, groups in the verification frame expected to verify that their mechanism is false and did not discuss other possible conclusions. Based on these observed behaviors, we defined the frames in terms of uncertainty in outcomes and epistemic agency.

III. RESULTS

We claim that lab groups operationalized the instructor's prompt for falsification by taking up one of two distinct epistemic frames: open outcome (one group) and verification (four groups). In this section, we provide example excerpts from two lab groups, one that takes up each frame. These episodes were chosen to represent each group's dominant frame throughout the activity and to illustrate the frames we identified, however each group may have shown evidence of other, short-lived epistemic frames during the activity as well. All student names are pseudonyms.

A. Open outcome frame

Henry (H) and Rylie (R) comprise the one group that finds an amplitude dependence in the first half of the lab session. Their current assignment is to determine whether friction at the pivot point of the pendulum is responsible for the observed amplitude dependence. At the beginning of the activity, they lay out the goal of their experiment:

R: Okay so pivot friction, so we're trying to prove that this is not impacting

H: Uh, so we are, we are going to, our, we're going to assume this has an impact, so we are trying to prove that it does not have an impact.

R: Okay, so trying to prove it does not

H: Trying to falsify the claim that the pivot friction has an effect.

Both Henry and Rylie initially expect to falsify their mechanism: they explicitly mention the goal of their experiment as trying to prove that friction does not have an impact on the period of the pendulum. This prompts the pair to design an experiment where they measure and compare the period of the pendulum with no added friction and with added friction with an amplitude of 10° and then 20°.

They first measure the period of the pendulum from each angle with no added friction. Then, the students add friction by rubbing chalk against the pivot point of the apparatus where the pendulum string is held in place by a small metal slit. As Henry and Rylie begin collecting data with added friction from 10°, they notice that their period measurements (time, in seconds, for one full pendulum swing) are longer than those from 10° with no added friction:

R: 1.16, 1.30, 1.22, 1.27, 1.26, 1.16.

H: Definitely a difference.

R: Yeah this is different. 1.27

H: Huge difference.

R: 1.23, 1.18, why is it so different?

H: I don't know, it's definitely a good thing.

To falsify friction as the mechanism responsible for the observed amplitude dependence, the group expects that the period with no added friction is indistinguishable from the period with added friction from each angle. Their incoming data suggest otherwise, however, leading Rylie to react with the question, "Why is it so different?". This reaction suggests that Rylie seeks an explanation for the discrepancy. On the other hand, Henry deems the difference a "good thing" despite it being at odds with their expectations. It is unclear why Henry considers the result good, but this utterance may demonstrate that Henry is comfortable with the idea that their expectation to falsify might not be achieved.

The students finish collecting their data and then calculate two t' values comparing the friction conditions from each angle. Rylie finds a distinguishable t' value (3.13) between the conditions from 10°, while Henry finds an indistinguishable t' value (0.5) between the conditions from 20°. They try to make sense of these conflicting results:

R: So maybe our hypothesis is that the friction has a bigger impact on smaller angles.

H: Yeah, well that kind of makes sense because the angle is kind of related to speed and speed is related to friction. Is speed related to friction? I don't know, probably.

R: Is speed related to friction? We can look it up.

H: Well speed is related to air friction.

R: Yeah, friction does depend on the speed.

H: We got it!

R: Friction is higher with more speed though.

The inconsistent results of their statistical analysis lead Rylie to draw a preliminary hypothesis that does not align with their expectations of falsification but is supported by their data: friction impacts the period more at smaller angles than at larger angles. The group also attempts to reconcile this unexpected outcome with physical reasoning. They relate friction to speed, discussing that when released from larger angles the pendulum is traveling faster and experiences more resistance from friction. The pair recognizes, however, that this logic predicts that friction more strongly impacts the period at larger angles – the opposite of what they found.

Given these discrepant results, Henry and Rylie decide to extend their investigation by increasing friction even more and collecting new data. They wedge a thick rag into the pivot and measure the period from 10°. They compare this data to their period measurements with no added friction from 10° from before, which results in a nearly distinguishable t' value (2.9). The group discusses the conclusions they can make:

R: 2.9, that means it is distinguishable.
H: But we also got a t' like less than 1.
R: For which, for 20?
H: For 20 degrees yeah, t' was 0.5.
R: Okay, so we're going to say for low angles we have high t' and for high angles we have low t' so it's possible that friction plays a difference, but there's still something unaccounted for.

Rylie acknowledges that they found different results from different angles and posits that "there's still something unaccounted for" in the observed amplitude dependence (i.e., that friction does not fully explain the dependence). In this way, the group draws appropriate conclusions from their data without favoring their or the instructor's initial expectations of falsification. The group's expectations for the experimental outcome, therefore, carry uncertainty. The pair also enacts epistemic agency by constructing new and unexpected knowledge from their data.

B. Verification frame

Another group of students – Alina (A), Sarah (S), and Carlos (C) – tests whether tension in the pendulum string explains the observed amplitude dependence. At the beginning of the activity, they discuss the goal of their experiment:

S: What does falsifiable mean again?
A: Uh, we're trying to see, to disprove it.
S: We're trying to disprove it?
A: Yeah and if we can't then we're like
S: Then it's right! Okay.
A: Or at least we haven't found anything that says it's not.

Similar to the group in the open outcome frame, these students have a clear aim in mind before beginning their experiment: they clarify that to falsify a claim is to disprove it.

They discuss their experimental design and decide to add mass to the pendulum bob to increase tension in the string. They will then measure and compare the period of the pendulum with and without this added tension from 20°. The group considers how this experiment will satisfy their expectations of falsification:

S: So, are you saying if we could like disprove tension itself affecting the period, then we can disprove that tension at different angles affects the period?
C & A: Yeah.
S: So we're falsifying the idea of tension itself affecting the period?
A: Yeah.
S: Cool, that works! That's explainable.
A: Yeah, exactly, well that's what we're going to go with.
S: It's like, we could go with anything, as long as we can B.S. it.

This conversation adds nuance to the first excerpt: the group expects to falsify their mechanism for the sake of satisfying the instructor and completing the assignment. Rather than enacting epistemic agency – taking control over the knowledge they are able to produce in this context – the group is content that their plan is something they "can B.S." in the lab notes.

Later, when the group collects and analyzes their data, they find a t' value of 2 between the periods with the lighter and heavier mass from 20°. This value means the data are inconclusive as to the effect of tension on the period. The group reacts with dissatisfaction and discusses how to make the t' value lower to agree with their goal of falsification (ellipses indicate unrelated speech occurs before the next line in the transcript):

S: I mean it could be worse, we could've gotten like eight or something.
A: Okay so if we use the standard, the other standard deviation, we get 0.637, but with the one, like with the little, but with the big one, then it becomes 2...
S: The standard deviation instead of the standard uncertainty...Unfortunately
A: We cannot do that.
S: That's not how the formula works, so. Two, okay, it could be worse...
S: We can say we reduced the uncertainty 'cause that would make the value higher right? So how could we do it to get it less distinguishable?

The group judges their results subjectively: Sarah says, "it could be worse." This reaction suggests that they are not satisfied with the outcome. In response, Alina manipulates the t' equation in an attempt to lower their value to their desired result. Alina finds that if they use the standard deviation instead of the standard uncertainty to calculate t', they get the smaller value they want. Though Sarah asserts that they cannot plug in the wrong uncertainty values to decrease the t', that Alina proposes and executes the calculation demonstrates an attempt to explicitly falsify their mechanism by manipulating uncertainty values. At the end of the conversation, moreover, Sarah goes as far to ask how they could "do it to get it less distinguishable." This comment is an overt bid to perform their experiment to achieve their expected outcome. Such reactions to unexpected data are contrary to those of the group in the open outcome frame, who responds with physical reasoning and a follow-up investigation.

Given their inconclusive t' value, the three students ask the TA what they can conclude in their lab notes. The TA clarifies that they cannot determine whether their two conditions are distinguishable, after which the group discusses how they will phrase their results in the lab notes:

A: Alright, so I guess we say 'it's likely' or 'possible' tension is, tension affects the angle, or like tension matters in

the angle.
S: So, tension may not affect the period of the pendulum. The tension at different angles may not affect the period of the pendulum.
A: But we also don't know that it doesn't.
S: I mean 'may not' is saying like may or may not.
A: Okay yeah let's just say 'may not' then cause we're trying to falsify it right?
S: We're trying to like influence [the TA's] mind.

Rather than appropriately claiming that they cannot determine if tension explains the amplitude dependence, the group considers how they can word their results to reflect the TA's prompt for falsification. They even admit that they are hedging their claims to convince the instructor that they found the correct outcome. This unjustified interpretation and manipulation of semantics reflects the group's view of their result as certain and their resistance to taking up epistemic agency.

IV. DISCUSSION AND CONCLUSION

In this study, we analyzed video recordings of an early-semester lab session to evaluate the effects of an instructor's attempt to shift students' epistemic frames. This instructor explicitly tried to shift students away from verifying the canonical model [14, 15, 20–24] by prompting students to design experiments to falsify the claim under investigation, in line with Popperian inquiry [29, 30]. Five out of seven lab groups in the session took up the instructor's prompt, some in ways aligned with the goals of inquiry-based labs [1–4] – the open outcome frame – and others not – the verification frame. These frames and their defining characteristics are likely generalizable beyond this lab session, based on their connections to prior work. We expect the falsification aspect of the frames, however, to be unique to this section based on the instructor's prompt.

Two key features of scientific inquiry distinguish the open outcome and verification frames we identified: uncertainty in outcomes [9] and epistemic agency [10–13]. This distinction closely resembles the contrast between "doing science" (open outcome) and "doing school" (verification) identified in prior work [34]. First, despite both frames involving similar expectations for the experimental outcome, falsification, the perceived uncertainty of this outcome varied. Groups in the open outcome frame discussed and revised their expectations of falsification when faced with evidence that supported other conclusions. In contrast, groups in the verification frame held firmly to their initial expectations despite their data suggesting other outcomes. Second, students in the open outcome frame acted as epistemic agents, while those in the verification frame did not. Upon collecting and analyzing experimental data, students in the open outcome frame reacted to unexpected results with questioning, physical reasoning, and a follow-up investigation. These students also drew conclusions supported by their data and not by their expectations – they constructed their own knowledge. Conversely, students in the verification frame reacted to inconclusive data with subjective judgment and data manipulation [14]. They also hedged their conclusions to satisfy the instructor, resisting the opportunity to generate alternative knowledge.

Rather than shifting students away from the confirmation frame [14, 15, 20–24], therefore, instructor prompts for frame shifts should focus on uncertainty in outcomes and epistemic agency. Prompting uncertainty in outcomes means normalizing the idea that scientific claims may carry limitations and simplifications – that the theories and models students learn in lecture should not be taken at face value [9]. While students may hold some initial expectations of the outcome of an experiment, these expectations should be tentative and subject to revision if data suggest another outcome. The second piece is epistemic agency: instructors should make students comfortable with the authority they have to form new and unexpected conclusions [10–13].

Our analysis also points to specific stages during labs as suitable for this kind of instructor intervention. We found substantial differences in the way students in each frame reacted to their data and statistical results, from manipulating calculations to physical reasoning. During data collection or analysis, therefore, may be a good time to gauge and redirect students' epistemic frames. Additionally, we observed distinct behaviors at the end of the session when students discussed what conclusion to report in the lab notes. Before students draw such conclusions, instructors may initiate a brief whole-class discussion about forming conclusions supported by experimental data regardless of any initial expectations.

The varying student responses we observed further suggest that the instructor's attempt to shift students' frames may have had unintended consequences. Henry and Rylie (the open outcome frame group) were the only ones that found an amplitude dependence in the earlier part of this lab session. These students, therefore, were already comfortable with falsifying claims they might expect to be true. The instructor also highly endorsed this group's work in front of the class and motivated the activity with this group's finding. These instructor moves likely contributed to this group's taking up a frame in line with scientific inquiry. On the other hand, Alina, Sarah, and Carlos (the verification frame group) did not find an amplitude dependence earlier in the lab. Thus, they were likely not comfortable with the idea that they could find and report a different result than the one predicted by the canonical model. These students then perceived the instructor's prompt for falsification as the experimental outcome they ought to find. Future work will closely examine the instructor's interactions with each group throughout this particular activity to determine whether and how specific instructor moves might have led students to take up each frame.

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