Using lesson design to change student approaches to dorm-room design prelabs

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Student approaches to design tasks depend heavily on context – including both physical and conceptual aspects. These effects have been studied in the classroom, but less so in a home setting, where an instructor is not present to facilitate students' design efforts. In this paper, we propose that manipulating contexts within a lesson may be an option to guide student behavior in an at-home setting. We describe an experiment where the order of an at-home assignment was altered to probe how setting contexts with equipment and content domain familiarity influence student approaches to design tasks. By switching the order of a calibration activity and open-ended design activity, we observed that increasing student content and equipment knowledge makes them more likely to choose more sophisticated analysis methods with the new equipment and topic, but also leads to an increase in investigations with surface features similar to the calibration.

Keywords: Home experiments, introductory physics laboratories.

I. INTRODUCTION

Design and inquiry tasks in the introductory physics laboratory aim to engage students in authentic science practices. However, these practices usually take place in a setting that is inauthentic both to the way people learn at home and the way science is practiced in a research laboratory. In laboratory reform efforts at the University of Illinois, we have incorporated at-home design tasks to encourage creative and exploratory approaches that are consistent with learning outside the classroom to prepare students to develop scientific practices in the classroom.

A challenge introduced by shifting from classroom design tasks to home design tasks is the presence – or lack – of an instructor. Design instruction, because of its inherently open-ended nature, carries the risk that students will make choices taking them in less productive directions. In a classroom setting this can be mitigated by an instructor, who can redirect or repurpose unproductive inquiry paths [1]. In the absence of an instructor it becomes relevant to consider other means that are available to guide students in their experimental tasks.

A variety of research from classroom settings indicates that the ways student engage in design tasks can be influenced by the additional context of their understanding. Perceived affordances – particularly the tools perceived as being available and useful for the task at hand – have been shown to constrain student solutions to design experiment tasks [2]. Student conceptual understanding of a topic and their ability to model the topic has also been shown to affect how systematically students proceed in their investigations [3]. This suggests that careful context control may be a way to mediate student design tasks at home while still giving them room to design and make their own choices.

In this paper we describe our efforts to understand how the controllable contexts we set in at-home assignments affect the ways students approach the design tasks. Using data from a blended laboratory format which uses at-home experiments as "prelabs" to prepare students for classroom experiments, we focus on a specific assignment that asks students to explore unfamiliar equipment and conceptual contexts. The assignment consists of two activities – a guided calibration task that scaffolds equipment training in the context of a new physics scenario, and an open-ended task to explore the new physics scenario.

To probe the context effects, we switched the order of the two activities and studied how this switch affected student answers to the open-ended task. We will discuss the ways students approached the task, detailing how the different context conditions affected student choice of data acquisition tools, analysis methods, and topic choice, as well as noting student propensity to repeat the calibration task's procedure in the open-ended task.

II. PRELAB EXPERIMENTS

The study described in this paper was conducted in a reformed introductory calculus-based mechanics laboratory serving primarily freshman science and engineering majors. In addition to doing experiments in the lab classroom, students are assigned prelab activities which involve experimental explorations at home. More details of the classroom portion of the lab reforms can be found in [4].

A. The lab equipment

Students in the laboratory sections were given portable data acquisition equipment – the Interactive Online Laboratory (IOLab) system – that they used with their personal computers to collect experimental data both in the home and in the classroom. Over the semester, students used a wheel encoder, an accelerometer, a force probe, and a gyroscope sensor, all built into the IOLab device, to collect experimental data. Software associated with the IOLab device was used to control data acquisition, display sensor results in real-time, and perform some simple analysis functions.

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B. Prelab purpose and implementation

Prelab assignments were designed to prepare students for their upcoming lab by developing knowledge and skills that would be integrated into their classroom experiments. To allow for flexibility in student approaches, prelab task prompts were written based on invention as preparation for future learning principles, which emphasize that the preparatory stage should give students a basis of experience to build upon, rather than focusing on students obtaining a single desired result [5].

Assignments were delivered through an online homework system, in which students could read the prompts and respond to them in free-response text entry boxes, and share their IOLab data with their instructor. Students completed their prelabs and received feedback from their instructor prior to the lab meeting. Full credit was given for reasonable effort on the assignment.

The nature of prelab assignments varied depending on the experience desired for the upcoming lab. Typically the assignments consisted of 2-3 "activities" including calibration checks, sensor explorations, and data we wished to bring to students' attention for sensemaking or practical skill acquisition purposes.

III. METHODS

The assignment discussed in this paper ("Prelab 7") was given to students prior to attending the 8th lab meeting of the semester. By this time, students have used their IOLab equipment in seven previous labs to study dynamics and energy topics by using the accelerometer, wheel sensor, and force probe, and have practiced using the software interface and its built-in analysis tools.

Prelab 7 consists of a guided gyroscope calibration activity and a somewhat open-ended discovery activity. This assignment was designed to prepare students for the classroom by introducing the gyroscope sensor and its function to study rotational motion. This prelab is the first time students are using the gyroscope sensor and the first time they are considering rotation in a data acquisition context (although they have been learning about rotation for 2 weeks in other components of the class).

The calibration activity guides students to calibrate their gyroscope sensor. To do this, students are instructed to collect gyroscope data as they carefully turn their IOLab device by a full rotation. Students are guided to the concept that the area under the curve of the angular velocity graph, i.e., the angular displacement, should be 2 pi radians and to adjust the calibration scaling factor to give this result. An example of a successful calibration result is shown in Fig. 1.

The open activity in the assignment prompts students to spin their IOLab and choose how to investigate the motion. Students are asked to list sensors that could be used, collect and share data with their instructor, describe some options for investigation, and finally to choose one option to investigate the spinning of the IOLab and do it. Students

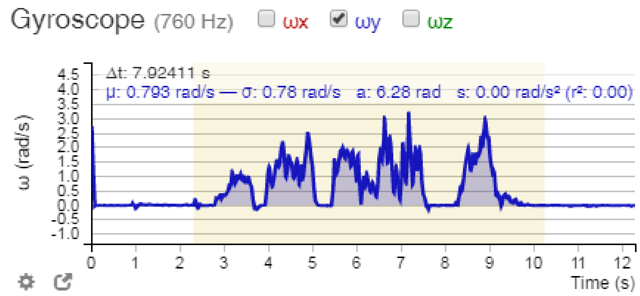

FIG 1. Calibration activity data using the software analysis tools to measure angular displacement.

were not given any guidance about preferred sensors or topics to explore in this activity.

A. Study conditions

For this study, we alternated the order of the two activities in different semesters. In two semesters (Spring 2016 N=79 and Spring 2017 N=74), the calibration activity preceded the open activity – we'll call this group "calibration first"; In one semester (Fall 2016 N=121) we switched the order so that the calibration activity followed the open activity – we'll call this group "open task first". The analysis described in this paper focuses on student answers to the final question in the open task.

Students in all three semesters used the same prelab and lab materials, but with different instructors. We note that student choices were indistinguishable between the two spring semesters combined in this study, and between all three semesters on a similar open-ended prelab question given earlier in the semester. Based on these comparisons, we assume that instructor and semester population should not significantly affect the outcome of this study.

B. Coding methods

Codes to understand student responses were developed based on identified contexts set by the calibration activity: (1) equipment practice and (2) situating rotation in an IOLab setting. The equipment practice encompasses both using the gyroscope (which is new to the students) and using the analysis tools to extract information from the sensor data (which the students have been doing in other physics contexts all semester).

Based on these identified contexts, we describe student answers to the final open activity question based on the following questions:

1. Which sensor(s) did the student use to collect data?
2. What methods did the student use to analyze or interpret their data?
3. What general physics topics does the student's measurement fit into?

We also identify students who found the angular displacement using area under the gyroscope data curve, as this was the same as the calibration task.

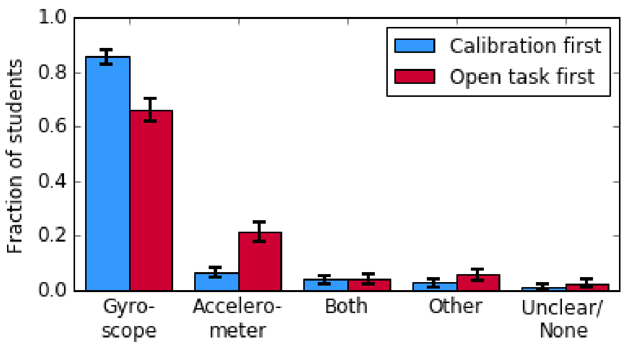

FIG 2. Frequency of student sensor choices to explore the rotation motion.

Student approaches were coded based on their written responses to the investigation task by two researchers who coded the responses individually and discussed disagreements until achieving 100% agreement. In cases where it was not clear which approach a student used, the researchers referred to student data shared in an online repository. Responses that could not be resolved in this way were recorded as 'unclear.'

IV. RESULTS

Results of this study are presented in this paper using analysis showing the frequency of students identified as choosing specific approaches to the open-ended exploration task. Results from the two semesters of Calibration first students were indistinguishable from each other, so for this analysis we combine them into one group.

A. Choice of investigation tools

We first looked at the sensors students used in their independent investigations. From reading student answers, we identified that students used the gyroscope and accelerometer sensors most frequently in their investigations. Use of the force probe and wheel sensors, as it occurred much less frequently (at a rate of 0-5% of the study groups), has been categorized as 'Other.'

Figure 2 shows the student sensor choices based on whether the students did the calibration first or the open task first. The gyroscope was generally preferred by all groups, however the calibration activity made students somewhat more likely to select the gyroscope for their investigation: 86±3% of Calibration first students used the gyroscope to investigate the rotation, compared to 66±4% of Open task first students, $\chi^2(1, N=274)=14.52$, $p<.001$. Students in the Open task first group were slightly more likely than the Calibration first students to make their measurements using the accelerometer instead, $\chi^2(1, N=274)=13.24$, $p=.001$.

To explore the methods students chose to interpret their data, we identified the tools and/or strategies described by students in their written work. Students from both groups most commonly used the built-in software tools to calculate the average, slope, or integral of a region of data ("Analysis tools"), or to read a single point value off a plot ("Point"). In addition to extracting numerical values using the software, several students chose to interpret their data qualitatively by making observations about the graphs displayed on their software ("Observation"). Results are shown in Fig. 3.

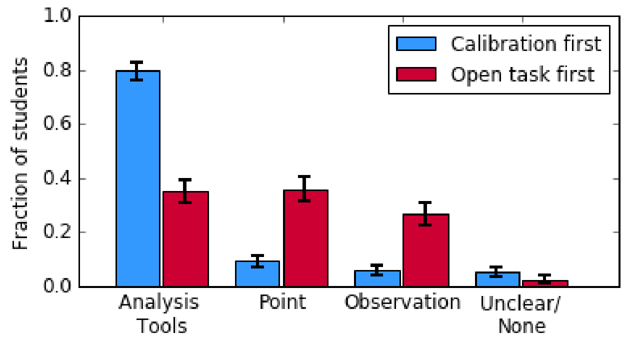

FIG 3. Student methods to analyze or interpret data.

Calibration first students chose to use the analysis tools more than any other method (80±3%, compared to 9±2% for point measurement, and 6±2% making observations), and used these tools 45±5% more often than the Open task first students, $\chi^2(1,N=274)=57.01$, $p<.001$. Open task first students were nearly equally likely to use any of the three methods (35±4% analysis tool; 36±4% point measurement; 27±4% observation), choosing point and observation methods with higher frequency than Calibration first students ($p<.001$ for both methods).

B. Choice of topic

Students chose to measure many different quantities, but in this paper we focus on general topic areas: rotational quantities (e.g. angular displacement or velocity), linear quantities (e.g. linear acceleration or force), and connections between rotational and linear quantities (e.g. using angular displacement to find tangential velocity). An additional "sensemaking" category has been introduced to represent students who did not make a specific measurement, but used the task as to make sense of the measurement outputs of the IOLab sensors when the device is rotated.

Results from student topic choices are shown in Fig. 4. Most students chose a rotation topic for their measurement: 80±3% Calibration first, 53±6% Open task first, $\chi^2(1,N=274)=24.53$, $p<.001$. Students who did the open task first were 8±4% more likely than Calibration first students to choose a linear measurement and 18±4% more likely to choose a sensemaking approach ($\chi^2(1, N=274)=4.294$, $p=.038$ and $\chi^2(1, N=274)=21.58$, $p<.001$, respectively).

C. Student repetition of the training task

Although most of our analysis looked at general topics rather than specific measurements, we did look to see whether students procedurally replicated the calibration

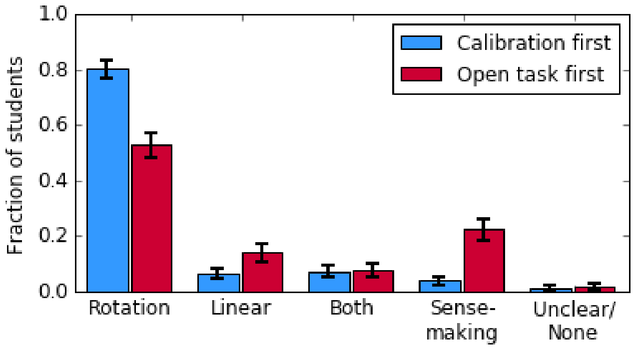

FIG 4. Student measurement choices generalized by topic of quantity measured.

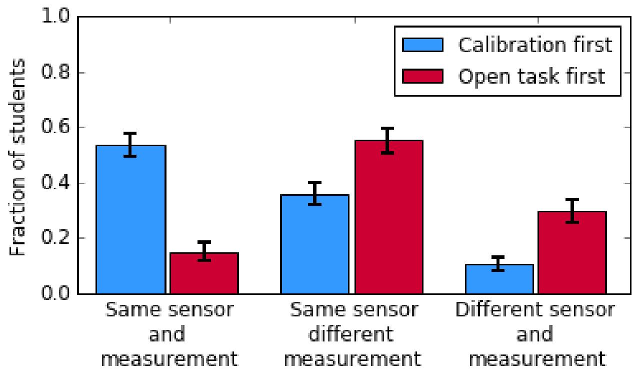

FIG 5. Frequency of student methods identical, close, and far from the calibration activity measurement.

activity. To provide a preliminary measure to consider how far students' investigation fell from the calibration method, we also considered the rates that students used the same sensor to measure a different quantity, and used a different sensor. Results are shown in Fig. 5.

Calibration first students chose to repeat the procedure learned in the calibration with very high frequency: 54±4% of students in this group made this specific measurement, compared to 15±3% of the Open task first students (χ^2(1, N=274)=43.70, p<.001). 36±4% of the Calibration first group used the gyroscope to measure something else. Open task first students tended to make more diverse measurement choices than Calibration first students, both with the gyroscope (55±5% measured something other than angular displacement) and by choosing to use other sensors (30±4%), Overall χ^2(2, N=274)=46.73, p<.001.

V. DISCUSSION AND CONCLUSIONS

Considering the results from this study as a whole, we see that placing the calibration activity prior to the open-ended activity had a large effect on student approaches to the open-ended activity. Students with the calibration activity first were much more likely to use the gyroscope sensor, to extract information from their data using the same analysis tools, and to measure a quantity related to rotation. More than half of the group chose to reproduce the exact measurement procedure used in the calibration.

We were surprised to see that many of the students who did the open-ended task chose to use the gyroscope without having any previous introduction to the sensor, although some students from this group chose to use the more familiar accelerometer sensor instead. Given the context of an unfamiliar sensor and a new type of motion to study, the Open task first students tended to focus on simpler analysis methods like qualitative descriptions and reading points off the graph. These simpler methods are not necessarily an undesirable outcome – for example, students who engaged in sensemaking about the sensor output could be considered to have chosen to train themselves about rotation with the IOLab system.

How we judge the outcomes from the two groups depends on the instructional goals of the prelab. If the objective is to encourage creative approaches, allowing students to explore the new equipment and ideas without a preparatory task may be ideal, especially if the preparatory task constrains many students to choose identical approaches. On the other hand, if the objective is for students to be prepared to use their equipment to explore a similar topic in class (as it is in our introductory physics labs), it may be better to place the calibration first to promote this outcome.

The results from this study indicate that, when students are working with new tools and ideas, the context set within an assignment can significantly affect the way they approach design tasks at home. Understanding these effects provides options for instructors to encourage productive outcomes from design tasks without being in the room while students work, while still giving freedom of choices in a design context.

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