When And How Do Students Engage In Sense-Making In A Physics Lab?

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Abstract. The Rutgers PAER group developed and implemented *ISLE* labs in which students design their own experiments being guided by self-assessment rubrics. Studies reported in 2004 and 2005 PERC proceedings showed that students in these labs acquire such scientific abilities as an ability to design an experiment, to analyze data, and to communicate. These studies concentrated mostly on analyzing students' writings evaluated by specially designed scientific abilities rubrics. The new question is whether the ISLE labs make students not only write like scientists but also engage in discussions and act like scientists: plan an experiment, validate assumptions, evaluate results, and revise the experiment if necessary. Another important question is whether these activities require a lot of cognitive and metacognitive efforts or are carried out superficially. To answer these questions we monitored students' activity during labs. (The work was supported by the NSF grants DUE 0241078 and REC 0529065.)

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INTRODUCTION

Investigative Science Learning Environment (*ISLE*) is a physics learning system which focuses on helping students acquire abilities used in the practice of science [1]. These abilities include an ability to design an experiment to investigate a phenomenon or to test a hypothesis, to collect and analyze data, to evaluate the effects of assumptions and uncertainties, and many others [2]. Students construct and test physics concepts by following a scientific investigation cycle in large room meetings and design their own experiments in labs [2]. Do they develop scientific abilities in such an environment? Previous studies that answered this question positively, used, as sources of data, students' writing in labs and on exams assessed by specially designed scientific abilities rubrics [3]. Do *ISLE* labs make students not only write like scientists but also engage in discussions and act like scientists? To answer this question, we monitored students' activity during labs.

Earlier, educational researchers monitored students' activity in a classroom and in laboratories to study metacognition [4-8]. Lippmann et al. studied the differences in student metacognition and sense-making in the labs where students designed their own experiments and where the experiments were prescribed by a write up. They found that focusing on sense-making episodes in labs is a productive and a reliable way to code student activities.

DESCRIPTION OF THE STUDY

The research was conducted in the labs that were integrated in two introductory physics courses for science majors. The population in the two courses is roughly similar but they are offered on two campuses of Rutgers University. Both courses have a 3-hour lab as a part of the course credits. During the time of the study the experimental course followed the *ISLE* curriculum [1] and the control course had traditional labs supplemented by reflective questions at the end. Below we describe the differences between the labs.

Control Course: Cookbook+Explanations Lab. In these labs students perform experiments by following well-written, clear and concise guidelines (Appendix A shows an excerpt from one of the write-ups) which instruct them on what and how to measure and how to record the data. The adjusted equipment and elaborate writes-up eliminate all possible difficulties such as parasite effects, wrong assumption effects and large uncertainty. In some labs students have to devise their own mathematical method to analyze data. After each part of the lab, students have to answer conceptual and reflective questions. TAs provide immediate help to the students when they have a question.

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Experimental course: design lab. *ISLE* laboratories are described in detail in [2, 3]. In these labs students design their own experiments. Write-ups do not contain instructions on how to perform the experiments; instead they guide students through various aspects of a typical experimental process (Appendix B shows an excerpt from an *ISLE* lab). At the end of each experiment students answer reflective questions that focus on different aspects of the procedure that they invented. In addition students use scientific abilities rubrics for guidance and self-assessment [2, 3]. TAs serve as facilitators.

Sample. We observed the behavior of 14 groups of students (one group per lab). Nine of the groups were in *ISLE* labs and 5 groups were in cook-book+explanation labs. Each observation lasted for an entire lab.

CODING AND LIMITATIONS

An observer sat with a student lab group timing and recording all student activities and conversations. After the lab was over, the field notes were rewritten and a complete transcript of each lab session was constructed. The analysis of the first transcripts revealed patterns in student activities that lead to devising codes for 4 categories of activities for the experimental course and 5 for the control course. Subsequent observations were analyzed using the coding scheme to note any behaviors that did not fit into the codes (we assumed that the presence of the observer did not affect student behavior). The last observations were made after the coding scheme was devised and we could not find any behaviors that did not fit the coding categories.

General codes*.* Our coding scheme turned out to be very similar to the one described in [4, 5]. Lippmann had making-sense, logistic and off-task codes. We observed similar types of activities. The only difference was that we subdivided the logistic code into two sub codes (procedure and writing).

Making sense – students' discussions about physics concepts, experimental design, the data, and the write-up questions.

Writing – students' descriptions of the experiment, data recording, calculations, and explanations.

Procedure – students gathering equipment, mounting set-up, and taking data.

Off-task – any activity that did not relate to the laboratory task.

In the control course we had to use one more code: **TA help** to note considerable time students spent listening to a TA explaining and answering questions.

b) Sense-making codes

We focused on the sense-making because it represents verbalization of the students' cognitive processes. The content of sense-making discussions was classified further according to the activities matching the descriptions of different scientific abilities (sense-making subcodes).

D – *Design*: Discussing experimental design and set-up, planning the experiment, etc.

M – *Model*: Choosing the mathematical model and the parameters to be measured.

A – *Assumptions*: Discussing assumptions in the mathematical model and their effects.

U – *Uncertainties*: Discussing sources and calculating values of experimental uncertainties.

Min – *Minimizing:* Discussing how to minimize uncertainties and the effects of the assumptions.

R – *Revising*: Discussing reasons for the discrepancy and the ways to improve the experimental design to get the discrepancy less than the uncertainty.

Examples of sense-making discussions related to the effects of assumptions on the experimental results.

ISLE Lab: Effect of assumptions
S1: I think we can ignore the friction.
S2: But we cannot ignore it. We account for it.
S1: No, it is too small.
TA: How can you check this?
S1: Let's measure the friction.
S2: How?
S1: Do you remember that lab where we measured it? We can tilt the track and measure the angle when the car starts sliding. *They tilt and observe that the car slides at an extremely small angle which they cannot measure.*
S2&S1: So, we can ignore the friction!

Cookbook+explanation lab: Effect of assumptions
S1: What temperature should we plug into the equation?
S2: 0°C
S1: How can you be sure that it is zero degrees?
S2: It should be. It is always 0°C.
S3: No. Ice can have much lower temperature.
S1&S2: Lets ask TA if we should take zero degrees.
TA: Yes, you can assume that it is 0°C.
Observer note: The lab manual: "Add some ice chips at 0°C to the tap water in the calorimeter". Thus, if students paid more attention to the write-up, they would not have this discussion.

Notice here that the beginnings of the discussions are very similar: students are exchanging their unfounded opinions and their discussion brings them nowhere. However the TAs' intrusions are very different. In the *ISLE* lab the TA triggers the next level of discussion by suggesting that students check their ideas. In the second episode, the TA answers the question. This makes any further sense-making unnecessary.

FINDINGS OF THE STUDY

Duration: Design lab versus a cookbook+explanation lab. Each lab in the control course had more experimental tasks, but it took students about half the time to complete each lab compared to *ISLE* labs (average of 80 min/lab versus 160 min). In *ISLE* labs students spent a great deal of time planning, discussing, and writing a detailed lab report. The experiments themselves took more time because students needed to improve them as they progressed (Fig.1). In *ISLE* labs, the students' interactions with TA were minimal (TAs did not provide explanations). Discussions similar to those shown above were considered as sense-making for both courses.

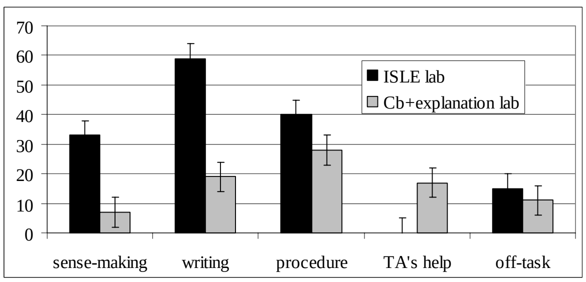

FIGURE 1. The time spent on different activities (in minutes). The data are averaged over the 14 groups sample.

Sense-making and scientific abilities. Figure 1 shows that students engaged in sense-making for about 33 minutes in *ISLE* labs - for 20% of the lab duration. In cookbook+explanation labs sense-making lasted for about 5-8 minutes, i.e. 9% of the actual lab time. The conceptual questions took on average 3 min. The time lines with the smallest increment of 1 minute supply detailed information on student activities. The typical time lines are shown on Fig. 2.

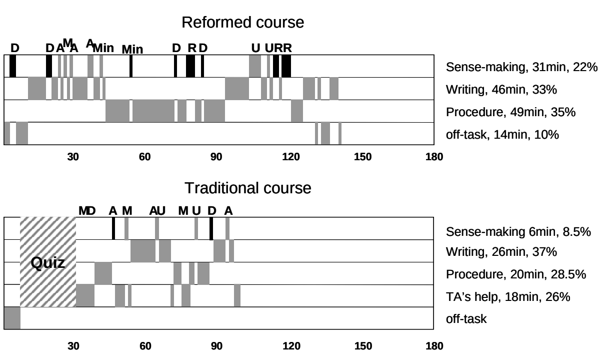

FIGURE 2. The typical time lines for different types of labs. Black color notes episodes of sense making that were not prompted by a write-up or a TA. The letters on the top of the timelines show the sense-making subcodes for each discussion episode.

The detailed analysis of the sense making episodes reveals differences between the courses. In the control course students engaged in sense making for a very short time. Few of their statements could be coded as related to scientific abilities. The TA explained the experiment design and the mathematical model. Although students had to answer questions about assumptions and uncertainties, they engaged in this activity superficially spending less than a minute on the discussions. That happened probably because students considered these questions unrelated to the experimental procedure. For *ISLE* students write-ups' questions about assumptions and uncertainties were crucial because they had to make a decision how to conduct the experiment and whether they needed to repeat it.

Another important difference was how often students switched to sense-making mode without prompting by TAs or questions in the manual. Such episodes of self-triggered sense-making are shown on the time lines by black color (Fig. 2). As experimental design required independent decisions. It is not surprising that these episodes happened more often in *ISLE* labs. The self-triggered sense-making often happened during periods of planning, executing, and revising an experiment.

Outcome of sense-making. A detailed analysis of the time lines reveals that sense-making episodes caused different student behavior in different labs. If we set aside the episodes of sense-making alternating with writing when students answered the manual questions and discussed their writings, we can see that in *ISLE* labs, sense-making discussions led to procedural changes, i.e. attempts to improve and revise the experiment or carrying out the next steps (Fig. 3a). In cookbook labs, in about 70% of such episodes the students' discussions led to asking a TA who provided an immediate answer (Fig. 3b). Thus *ISLE* labs make students pose questions and answer them, whereas in cookbook labs students seldom pose rare questions and do not tend to search for answers.

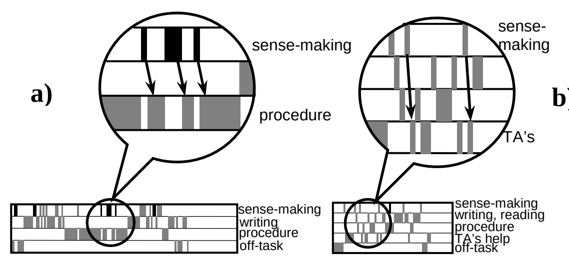

FIGURE 3. Sense-making outcomes: a) in *ISLE* labs sense-making causes a discussion which leads to a decision and to an execution; b) in cookbook labs sense-making causes TA's help mode with a TA answering and explaining.

DISCUSSION

Those who have tried to implement labs where students design their own experiments know how difficult it is. Students get frustrated with the design process, especially at the beginning. They want clear directions and clean experiments. Is this struggle worth the effort? Our findings show a dramatic difference between the behaviors and discussions of students in the labs where they had to design their own experiments and where the design was provided to them. *ISLE* students act very much like scientists in labs. They design an experiment spending time on careful planning and paying attention to details. They consider assumptions inherent in a mathematical model and try to devise a procedure to minimize the effect of assumptions. They consider experimental uncertainty while comparing results of two independent experiments and make a decision whether they have to improve and repeat the experiment. They spent a great deal of time writing lab reports to communicate the details of the experiment. We have observed that all these activities took significant amount of time and discussion.

The traditional labs, even supplemented with conceptual and reflection questions, did not engage students in developing these scientific abilities. They did not spend time choosing strategy, validating results and improving design. The discussions about additional conceptual questions are very brief so they do not make large difference.

Maybe the design labs are worth the effort.

REFERENCES

1. E. Etkina and A. Van Heuvelen, *Proceedings of the 2001 Physics Education Research Conference*. Rochester, NY, PERC publishing, 17-21 (2001).
2. E. Etkina, A. Van Heuvelen, S. White-Brahmia, D. T. Brookes, M. Gentile, S. Murthy, D. Rosengrant, and A. Warren, Phys. Rev. ST Phys. Educ. Res. **2**, 020103 (2006).
3. S. Murthy and E. Etkina, 2004 Physics Education Research conference, edited by J. Marx, P. Heron, and S. Franklin, *AIP Conference Proceedings*, **790**, 133-136 (2005).
4. Rebecca Lippmann and the Physics Education Research Group, "Analyzing students' use of metacognition during laboratory activities," AREA Meeting, New Orleans, April 2002.
5. R. Lippmann Kung, A. Danielson, and C. Linder," Metacognition in the student laboratory: is increase metacognition necessarily better?", EARLI symposium August 2005.
6. V. Otero, "The process of learning static electricity and the role of the computer stimulator," Ph.D. Thesis, San Diego University, 2001.
7. A. F. Artzt and E. Armour-Thomas, *Cognition and Instruction*, **9**, 137-175 (1992).
8. P. Adey and M. Shayer, *Cognition and instruction*, **11**, 1-29 (1993).

Appendix A: Cookbook+Explanation Lab.

Thermal inertia: The heat capacity of aluminum

1. Use the following table to record your data (omitted here).
2. Fill the calorimeter about ¾ full with tap water.
3. Record the mass of the calorimeter and water ($m_{water+Cal}$.).
4. Record the initial temperature of the water (T_{water}).
5. Place a hot piece of aluminum, which you can obtain from the boiling water bath, in the calorimeter and cover it immediately. Notice that you need to record the temperature of the aluminum piece for later calculations.
6. Shake the water making sure you move the piece of aluminum so that the water/aluminum system may come to thermal equilibrium.
7. After **3 minutes** record the final temperature (T_{equ}).
8. Obtain the mass of the calorimeter, water and aluminum ($m_{Al+Water+Cal}$).
9. Devise a method to determine the specific heat of aluminum, and compare it with the specific heat of aluminum in the text book. Find percentage difference.

Questions

1. What assumptions did you have to make to derive the formula for the heat capacity of aluminum?
2. Are there any ways to reduce the error it this minilab?
3. Suppose you put a block of iron and block of Styrofoam in the freezer and allow them to stay for a little while. If you gripped both blocks which one would feel warmer? Explain why.

Appendix B: Design (ISLE) lab.

Specific heat capacity of unknown object

Design two independent experiments to determine the specific heat capacity of the given object. The material the object is not known.

Equipment: Water, ice, beaker, hot plate, Styrofoam container with a lid, weighing balance, and thermometer.

First, recall why it is important to design *two* experiments to determine a quantity. Play with the equipment to find how you can use it to achieve the goal of the experiment. Come up with as many designs as possible. Choose the best two designs. Indicate the criteria that you used for the decision. For each method, write the following in your lab-report:

a) A verbal description and a labeled sketch of the design.
b) The mathematical procedure you will use.
c) All assumptions you have made in your procedure.
d) Sources of experimental uncertainty. How would you minimize uncertainties?
e) Perform the experiment. Try to minimize experimental uncertainties. Record your measurements in an appropriate format.
f) Calculate the specific heat capacity.
g) After you have done both experiments, compare the two outcomes. Discuss if they are close to each other within your experimental uncertainty. If not, explain what might have gone wrong. If your results are not close, perform the experiment again taking steps to improve your design.