Analyzing students' use of metacognition during laboratory activities

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In this paper we use a discourse analysis tool to investigate student behavior in different types of laboratories, from more traditional to free inquiry labs. We also correlate students' behavior with their explicit metacognitive statements, which allows us to differentiate between productive and unproductive metacognition.

Introduction

Laboratory activities are typically very different from other components of a class (lecture and recitation): they last longer, are self-paced, and require students to work in groups to complete a task. All of these things make it important for students to be metacognitive about their activities during lab. If they don't know what their goal is, what they are currently doing, what they should be doing next, and how that will help them reach their goal, they are less likely to benefit from lab. In this paper, we present a method for analyzing student's work during lab that will help determine if the type of lab causes a student to be more metacognitive or act in a more or less productive manner.

This investigation takes place within the context of a larger project, *Learning How to Learn Science: Physics for bioscience majors*. In this project, the University of Maryland Physics Education Research Group is studying how to modify introductory algebra-based physics to teach students to use productive processes for learning science. Such processes include seeking consistency between two ideas, using different representations, modeling, and pursuing the implications of a theory. In order to teach students to use these, we create an environment where students realize the need for such skills and are rewarded for using them. *Scientific community labs* are an attempt to create such an environment. This specific investigation focuses on whether the design of the scientific community laboratory (task, method, grading, topic, *etc*.) fosters productive metacognition and sense-making.

Context

Scientific community labs attempt to create a scientific community in which students design their own methods to answer questions and then defend their method and results to other students. To achieve this goal all the laboratory questions are set in a real world context and can possibly be answered using several different methods. The students are given a paragraph setting up the

* Work supported in part by NSF grant REC-0087519

research question and then an outline of the structure of the period. (See Fig. 1.) They are expected to interpret the question, design and perform their experiment, and analyze their data as a group, with help from the TA. If we design the research questions correctly, the five groups in each class typically invent at least three different experimental methods. The last 45 minutes of lab is devoted to a class discussion in which each group presents to the other groups who are expected to critique the presenters' method and analysis.

In this investigation, scientific community labs are compared to two other types of labs (*cookbook*, and *cookbook+explanation*) which are taken from other, more traditional sections of the same algebra-based physics course taught at the University of Maryland. In cookbook laboratories students are given a handout that describes the equipment they are to use and the steps they are to follow. Cookbook+explanation (*C+E*) labs were taught by a TA who changed the lab book by inserting 'explain why this happens' types of questions while cutting some of what she deemed 'busy work'. Typical examples of each of these laboratories are chosen, and one group of students working in each lab is analyzed.

Coding Scheme

Students are videotaped working in groups of two to four. The tapes are then transcribed, time stamped, and coded using a coding scheme derived from Schoenfeld (1985). Instead of analyzing student comments line by line, each statement is taken within the larger context and analyzed to see what the majority 'mode' is for the group of students. Our coding scheme classifies a group as being in one of three modes: Off-Task, Logistics, and Sense-Making. The *sense-making* mode is defined by Otero (2001) as including "discussions or utterances that were based on real or hypothetical experiences, peer instruction, and discussions or utterances about inconsistencies or unresolved issues." Among other things, students can be making sense of formulas, physics concepts, their experimental design, or their data. While in the sense-making mode, students may or may not be correct or successful, but they are using resources that are frequently productive for learning science. One example of sense-making occurred during a lab on interference, where a student was looking at the pattern made by light going through 2, 3, 4, or 5 slits. She saw that the patterns were all similar, and said "there's more slits, but because they're the same distance apart each time it's not going to change the interference pattern because they're hitting the same pattern. So it's just like reinforcing the same pattern that was already there."

Although we designed the scientific community labs to encourage sense-making, students frequently have to be doing other activities such as reading, writing, taking data, gathering equipment, performing calculations, and reporting to the laboratory teaching assistant. Such activities are coded as *logistics*. The third mode is *off-task*. A group of students that seems to be in a mixed mode, where one student is trying to make sense and the other students are wandering, asking the TA, and playing with equipment is coded as being in logistics mode because that is the majority group mode. While in any of these three modes, students may show explicit metacognitive behavior such as evaluating another student's reasoning, evaluating their own understanding, explicit planning, or evaluating the laboratory procedure. One example comes from a lab in which students evaluated their procedure for timing cans rolling down a ramp: "Those are really great numbers, but I don't think they're right because it was kind of, last time it hadn't really started rolling yet."

This coding scheme is designed for use while students are in control of their activity, as often occurs during a laboratory but not during a lecture. Thus, it is not used for the first part of a traditional lab where a TA typically gives a short lecture introducing the lab, or during the last part of the scientific community labs when there is a class discussion. Of the six labs presented here, two are coded by two different people, with an inter-rater reliability of 90% and 95%. After discussion, the two codings agreed by 96% and 98%. Metacognition markings are much more difficult to code reliably, partly since metacognition is harder to define. In one lab, both coders identified 24 metacognitive statements, but only 12 of those identified the same statements. In another lab one coder identified 56, another coder 21, and 18 agreed. To somewhat alleviate this problem, only those statements on which both coders agree are taken as metacognitive.

Results

In general, it seems that students spend more time sense-making and make more metacognitive statements in the scientific community labs. Table 1 shows the percent of time spent on sense-making, logistics, or off-task behavior. The last column shows the number of statements coded metacognitive per hour of lab time. However, this number should be treated carefully because of the reliability problems with metacognitive coding.

Lab Type	% Sense-making	% Logistics	% Off-task	Meta/hr
Cookbook	4	85	11	8
Cookbook+Expl 1	17	77	6	12
Cookbook+Expl 2	38	62	0	9
Sci. Community 1	20	78	2	12
Sci. Community 2	21	77	2	18

Table 1: Student activity in different labs

I. Case study: Veronica and Carl

In the cookbook lab, as one would expect, students spend little time on sense-making and a lot of time on logistics. However, it is surprising how the C+E labs activate such a large amount of sense-making. To look more deeply at these labs, we use a time-line representation. (See fig. 2) Time spent in each mode is shown as a bar, and metacognitive statements are identified by inverted triangles on top of the bar. In the first C+E lab (fig. 3) students used a magnet to induce current in a coil of wire connected to a galvanometer. The students, Veronica and Carl, spend all their time in the logistics mode until they come to the modified section of the lab. Here the TA asked them to first predict the direction of the induced current and then explain how the current was being induced, writing "a paragraph as if you were explaining this to someone who didn't understand this but was in physics." Veronica and Carl are also the students in the second C+E Lab (fig. 4). For this lab, the TA rewrote the whole lab, requiring them to explain their reasoning after every new observation. These questions apparently forced the students to go into sense-making mode more frequently. In other class activities, Veronica frequently makes sense using her real world experience. During one activity another student in her group thought common sense was not productive to use in that context, and instead was trying to make it "physics oriented." Veronica responded "It is, it is physics-oriented. That's just the way it is," and convinced her group to use the common sense explanation. However, in the cookbook lab setting, she only attempts to make sense when she is forced to by a specific question. In fact, for their first transition in the second C+E lab it is Carl (C) who points out the "explain why" question in the lab manual, causing Veronica (V) to start sense-making:

> C: So the angle theta decreases, right?
> V: I don't know….
> C: Why? **She [TA] said why** is the space between the spots rising. [points at lab manual]
> V: Between each one, it's just there's more light coming through for a wider one so more light rays interfere….
> [emphasis added]

The percentage of time spent in sense-making in the second C+E lab is greater than in any of the other labs shown here. Transitions to sense-making coincide with the lab questions "explain why this happens," "predict what it will look like," and "do these trends make sense". This indicates that the rewritten lab manual set the frame for Veronica to believe sense-making was appropriate and useful in this situation, and so she went into sense-making mode much more than in previous labs. She noticed this herself, and commented in the middle of the lab "I like this lab. This lab makes so much sense to me. More than other labs." Because Veronica was an excellent student it was very easy for her to go into a sense-making mode, (it just took rewriting the lab manual). Also, once she was trying to make sense, she was likely to be successful. For many of the other students in this lab this change did not activate sense-making. Instead they used their old strategies of lab survival: ask the TA, ask other students, and read more in the manual. These old strategies can be seen by looking at the questions asked to Veronica and Carl by the lab group in front of them. During the second C+E lab, these questions all concerned low level logistical information, such as "For number three, what kind of picture does she [TA] want?" and "For the second question, are they just asking for when you do one slit?". This lab group was unable to make sense, and instead was struggling to follow steps.

II. Productive Metacognition

The Scientific Community labs allowed the students to be in complete control of what they did during the first hour. The students were required to plan their method, take data, and form conclusions to prepare for their presentation during the class discussion. There was no lab book or lab questions to force them into sense-making mode. So, what was it that caused them to switch from logistics to sense-making? The time-line for Scientific Community Lab 1 (fig. 5.) shows the first transition from logistics to sense-making occurring around 22 minutes. During this lab the students were trying to figure out if two identical-appearing cylinders had the same configuration of mass inside. Until this time the students have been individually trying to weigh the cylinders in their hands, asking the TA for help, and attempting to understand the lab question. Student 1 activates sense-making mode by asking a clarifying planning question, which is coded as metacognitive. This question causes the rest of the group to start to work together to figure out a procedure.

1 What's our planned procedure?

3 We could find the acceleration

2 You don't know the mass.

3 You don't need the mass to find the average acceleration.

2 Isn't it?

3 No, if we just do velocity over time, and then we get the acceleration, and then, we don't know the mass, but we could find out the force, well, if we race them, are they going to roll at the same speed?

There were several metacognitive statements before this one that failed to activate sense-making. These statements were unproductive, likely because the rest of the group was too confused to go into sense-making or because the metacognitive statement was not a good activator.

Another productive metacognitive statement took place around 51 minutes. The students were racing the two cans down a ramp to see which can won. Student 1 admits confusion and asks the group for an explanation. This sends the group into sense-making mode.

3 [Can] 11 still wins. [Can] Nine can't keep up with us.

1 I'm just confused why it was tied before.

3 It's probably the way you were releasing it.

4 If you see the instant replay [the starting gate] was actually pushing [the cylinder] a little bit.

By admitting confusion, student 1 causes the group to move from taking data to making sense of their data and proposing causes for it.

Conclusion

Since there is no lab manual, questions in the lab manual cannot activate sense-making in the Scientific Community labs. Instead the students' comments themselves must cause the change. The time-line representation shows whenever a metacognitive statement is productive and activates a transition into sense-making. Metacognition that occurs while in the sense-making mode is frequently productive, but cannot cause the group to change modes because there does not exist a more productive mode in this coding scheme. However, it can cause other changes: for example, an evaluation of their data-taking method might lead the group to revise their method. This definition of productive allows one to determine how many of the statements coded metacognitive are productive by looking at the time-line representation. In figures 2 through 6 the metacognition markings that caused a transition are circled. Comparing the productive metacognition in the five labs shows that the scientific community labs were successful in creating a frame where students were more likely to use productive metacognition

Using the coding scheme presented here, we were able to show that students' use of sense-making depends on the laboratory frame, as shown by Veronica and Carl in tutorial or in lab, and by students behaving differently in the different laboratory types. The coding scheme also identifies productive metacognition as metacognition that causes a change in student's behavior, and shows that students are more likely to use productive metacognition in the scientific community labs.

References:

Otero, V.K. “The Process of learning about static electricity and the role of the computer simulator” Unpublished Doctoral Dissertation, San Diego State University and University of California, San Diego (2001)

Schoenfeld, A.H. “Mathematical problem solving” New York: Academic Press, Inc (1985)

Figures:

Lab V: Rolling Canundrum

You are an extremely thrifty shopper and often buy ‘mystery cans’, those cans whose labels have fallen off and are thus being sold for very low prices. Unfortunately, these cans often turn out to be tomato paste, to which you happen to be allergic. You want to figure out a way to test if the can could possibly contain tomato paste.

Question:

Are the insides of your two cylinders the same or different?
Each pair will bet a tenth of this lab’s grade on their answer.

I. Home Experiment Synthesis: 5 min Whole Class

Come into class ready to discuss the results from your home experiment

II. Board Meeting: 15 min Groups of 4

Each pair will measure two mystery cylinders.
How will you determine if the insides are the same or not?

III. Carrying out the Experiment 40 min Pairs

Make sure you will be ready at the beginning of the second hour to present your conclusions about whether or not your cylinders are the same.

IV. Class Discussion Whole Class

After the class discussion, write your final conclusion on a piece of paper you will hand in with your names and the cylinder’s numbers.

V. Evaluate and Reconsider: Groups of 4

How could you improve your ability to differentiate between cylinders? Plan your revision.
How could you improve your experimental design?
How could you improve your data collection?
How could you improve your analysis and presentation of your old data?
How could you make better arguments in support of your conclusions?
Come up with something for each of these questions.

Fig 1. Example of a Scientific Community lab

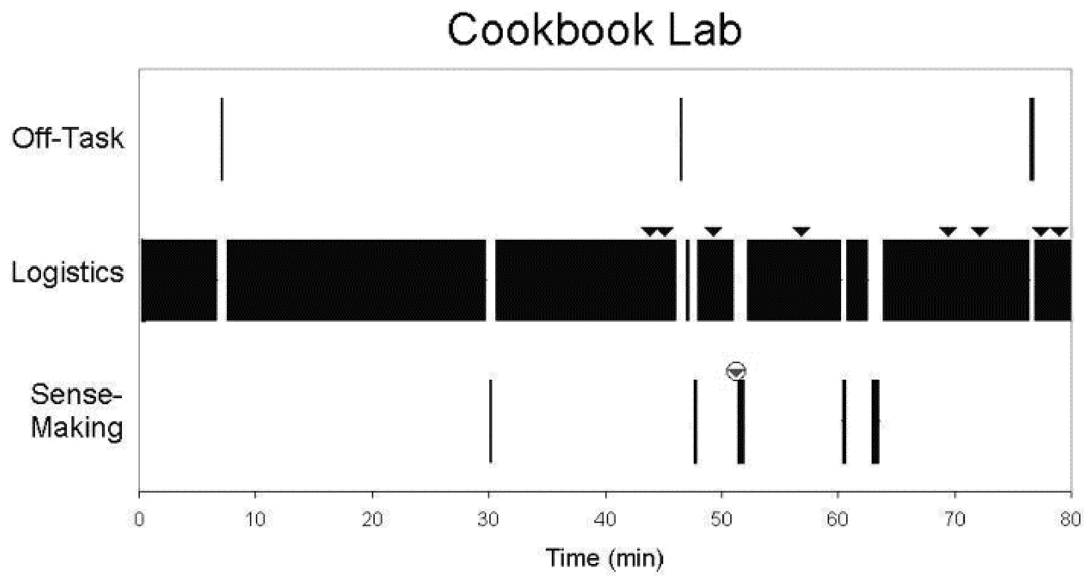

Fig 2. Time-line for the Traditional Lab

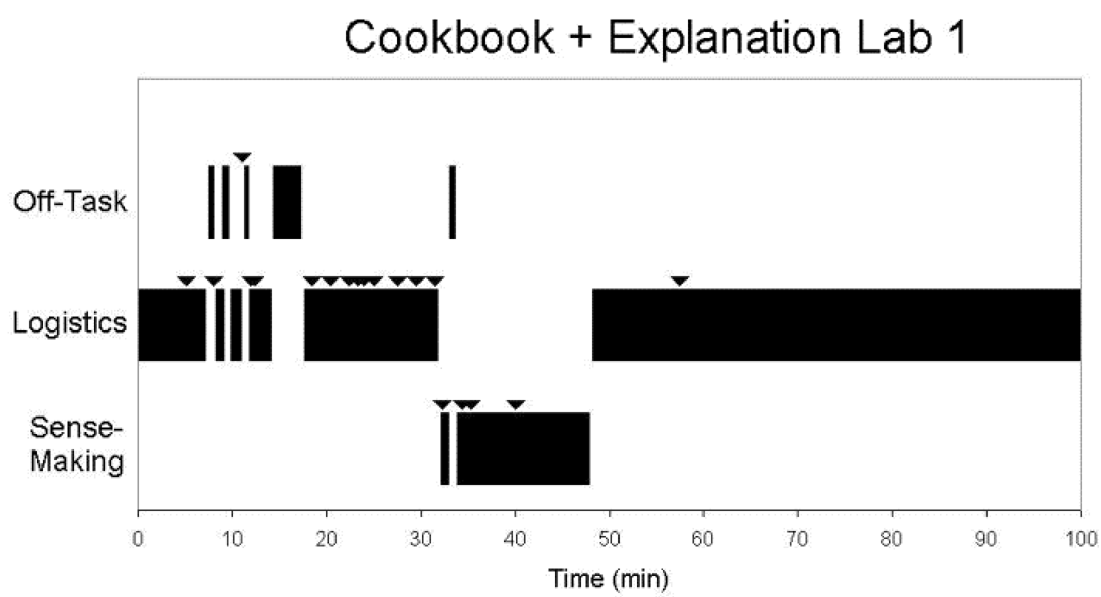

Fig 3. Time-line for the first Cookbook+explanation Lab

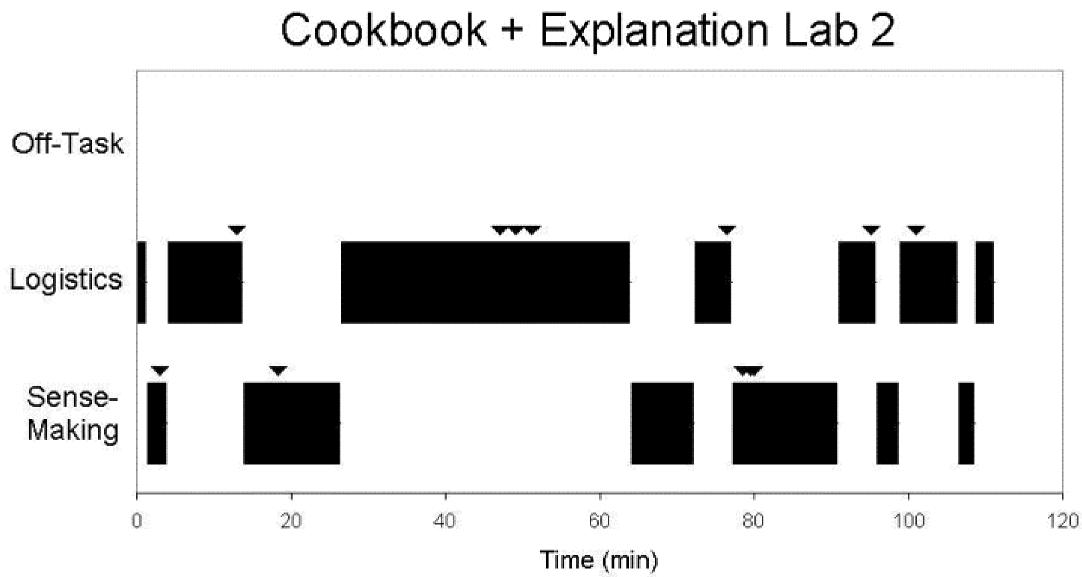

Fig 4. Time-line for the second Cookbook + explanation Lab

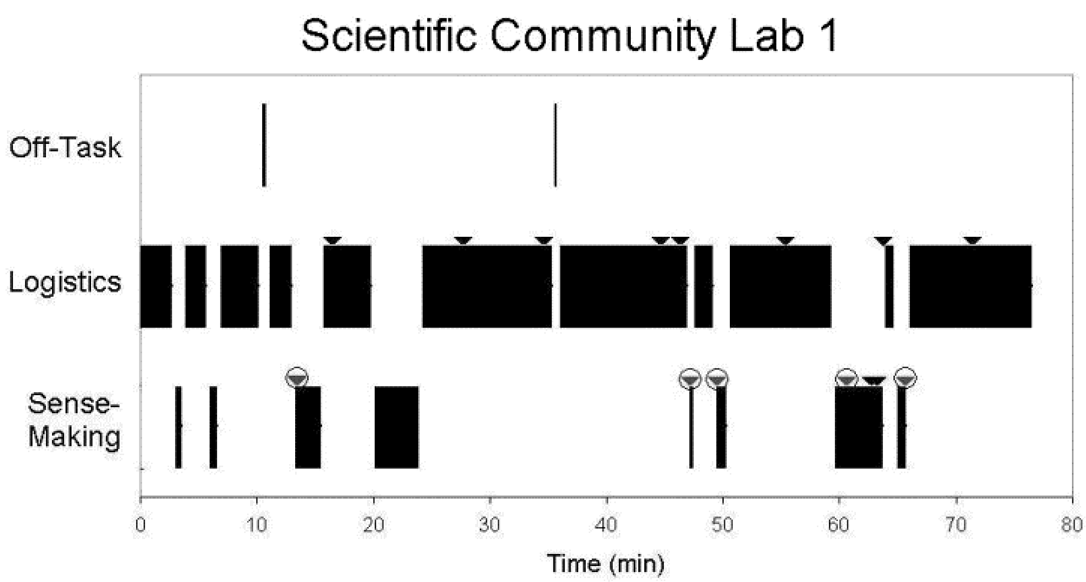

Fig 5. Time-line for the first Scientific community Lab

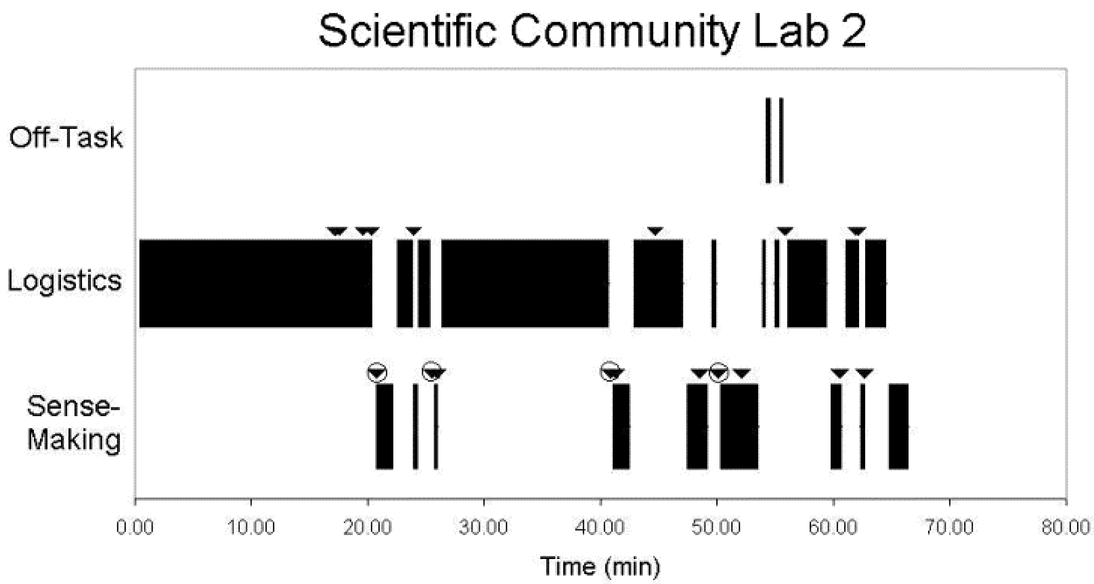

Fig 6. Time-line for the second Scientific Community Lab