FRAMING DISCOURSE FOR OPTIMAL LEARNING IN SCIENCE AND MATHEMATICS

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CONCLUSIONS

When I embarked on this research, I wanted to find out how students used metaphors to help them reason about space and time. I thought I would hear and see evidence of metaphor use surrounding the preparation and sharing of whiteboards—one of the 'universal constants' found in modeling instruction classrooms.

What I found in the first few videotapes I collected of the high school honors physics class initially frustrated me. The kinematics students I observed did not waste much time thinking about space or time. They identified it, assigned it a symbol, plugged it in to the equation they hoped was the right one, did some algebra with it and produced The Answer. The metaphors they used were the basic grounding metaphors of arithmetic (problem solving as object collection, construction, measurement or path following) and the object of metaphorical reference was the physics problem itself. Their problem spaces were containers from which they took the things they needed to reach their goal, and then they plunged into a mathematical 'wormhole', emerging at the far end with an answer. The problem space itself remained largely unexplored. Once they entered the spatial or temporal quantities they had collected into an equation, these quantities lost their connection to reality—they might as well have been 'slithy toves' or 'dilithium'.

The algebraic formulations of the problems they solved were the focal points of their whiteboard presentations. Graphs, diagrams and drawings, the SRs of physics, frequently occupied small, out of the way places on their whiteboards (and sometimes were absent altogether) while the algebra was featured prominently, and every step in the algebraic manipulations that led to a solution was shown and described.

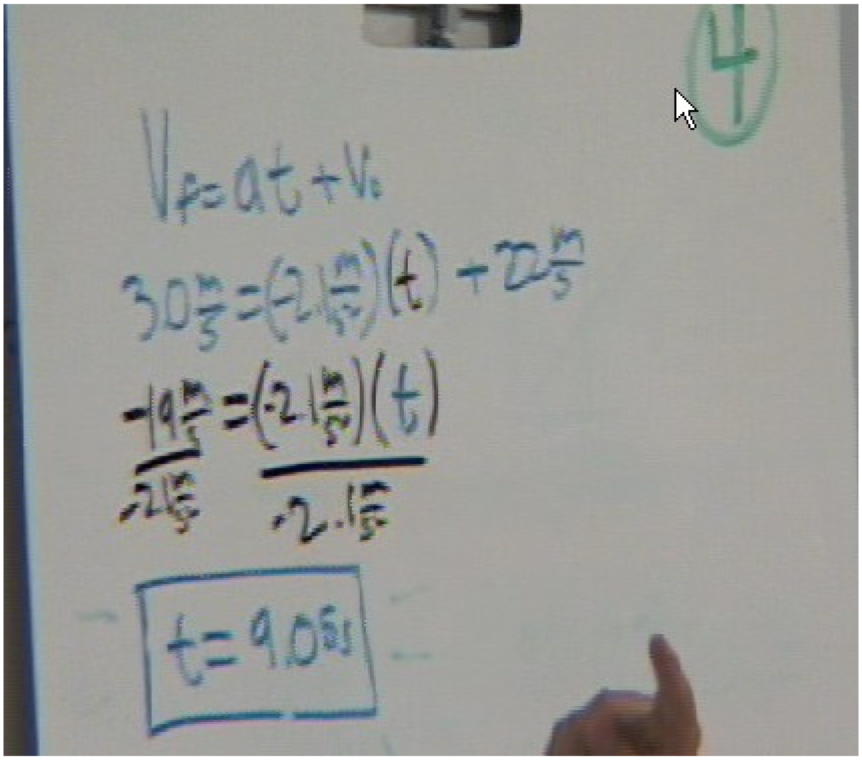

Figure 1. SRs were sometimes absent altogether while algebra was featured prominently on whiteboards.

The Value of Spatial Representations

As I added more videotapes to my data set, I began to see that students valued SRs in different ways. I saw that their values shifted over time to a greater appreciation of, and reliance upon SRs. Some students used SRs to justify their reasoning while others preferred to use computations. This led me to listen carefully to what students talked about, what counted for them as justification for the choices they made, and to whom they spoke and during whiteboard preparation and sharing, and this gave me some sense of how the SRs they employed functioned to keep them more grounded in the problem space.

At the most elementary level, students drew SRs on their whiteboards because they were required to do so. If they did not include the appropriate diagram or graph on their whiteboard, it would be incomplete and therefore incorrect (i.e., it would not receive full credit). *SRs, then, were about following directions.*

Making SRs might also be about demonstrating a skill. Just as a student might have some computational skill that she demonstrated by setting up and solving equations, she might also possess the skill of drawing an accurate, good-looking graph or diagram. *SRs, in this case, were about showing off.*

Occasionally SRs helped students set up a geometric solution to a problem, i.e., determining the area under a curve. Such solutions were dependent on a student's facility with unitization and thus hinted that some measure of spatial or temporal reasoning was an influence on their choice of solution strategy. Generally, however, they were simply used to justify the use of a certain algebraic formulation of the data. At least this approach included the mapping of graphical representations of space or time to algebraic symbols. *SRs, in this instance, were for justifying equations.*

In all the cases mentioned above, SRs, when they were included, were about getting answers. Moreover, the focus of students' presentations of these whiteboards was The Answer (in particular, the number—units were often overlooked) they had computed. Students who focused on answers were "zoomed in". Their view of the problem space was very limited, and their answers were not well connected to the problem spaces that gave rise to them. They could zoom back out if prompted but it was effortful, and they were unlikely to do so of their own accord.

As students became more sophisticated modelers, however, SRs were about constructing useful visualizations of physical situations in order to reason about them. When this grew to be the case, the first thing to appear on a whiteboard was the SR, and as it was constructed, its various features and their properties were identified and defined, often in writing. The SR served to keep them zoomed out so that the physical context of the problem remained actively in view in the problem space. Only after this setting of the scene was complete (by the construction of an SR that encoded the elements of the model and their relationships) did students zoom in, abstract out physical quantities and assemble them into a symbolical representation—an equation. Once they had a sensible equation that flowed from the diagram and obeyed the constraints placed on each of its elements by the definitions and properties that were assigned, they were done. Plugging in actual numerical data and solving for some value was, at times, an afterthought. In some cases, it was not even called for in the tasks students were assigned. *SRs in these instances were for visualizing and making sense of a problem space.*

SRs in this last instance were also an important communication tool in the distributed cognitive sense. There was, at times, a sort of dialogue between the students and their inscription that caused the inscription to evolve as reasoning aloud progressed. In addition to the students working together to create these SRs, the SRs they created functioned as another voice in the exchange of ideas—often a constraining voice that placed limits on the mental models that students were attempting to articulate. One thing that made this dialectic particularly valuable was the opportunity for students to 'ask' their SRs questions.

There were many types of questions that students asked in the course of creating and reasoning with SRs. Largely, it appeared that they learned how to ask these questions by imitating the kinds of questioning that their teacher practiced. If the teacher asked fill-in-the-blanks information questions, then that was the kind of questioning they used with each other when creating their whiteboard. If the teacher asked meaning questions or implication questions, then those were the types of questions they were most apt to use with each other when whiteboarding.

Whiteboard sharing with the whole class was substantially different for these two types of collaborations. When SRs appeared first on their whiteboards, students tended to describe how they reasoned through the problem based on their SRs. As a result, they were more apt to be asked questions by other students (or by the teacher) about their diagrammatic choices and interpretations. This resulted in discourse that was more focused on conceptual models and less on procedures. There was rarely a question about a formula or a disagreement about mathematics. When they ran into a physical situation that was counter-intuitive, they would zoom in and look to the mathematics for clues about what mattered, but until they reached some impasse, their reasoning stayed connected with the system schema and its physical interpretation when talking about the models they were constructing. Coordination of representations was possible when their SRs had more than superficial meaning to them.

Implications for Instruction

Modeling instruction can be a powerful instructional practice, but just as in problem solving, we must stay zoomed out. Our primary focal plane or frame must be the model—model construction, model elaboration and model deployment. This is the teacher's problem space. When we zoom in and fix our focus on details such as computation or the meanings of individual words, we signal to our students that this is where their focus ought to be also—this is what counts. I do not mean to imply that these things are not important, just that they need to be placed in perspective in the bigger picture. We must never forget to zoom back out our primary frame—the model—and help students to do so as well.

Often, teachers describe Modeling Instruction as if it were a technique, a skill or craft. They discuss discourse management techniques, teacher questioning, whiteboarding rules, grading, using technology, pre-lab demonstrations, tricks for explaining concepts (i.e., negative acceleration, Newton's laws), scheduling and time management, etc. It is easy to fall into the habit of looking at Modeling Instruction in terms of teacher performance rather than student thinking.

There is a theory about teacher professional development (Fuller & Brown, 1975) that suggests we go through three distinct phases in learning to teach: concern for self, concern for task and concern for students. Even an experienced teacher goes through this developmental sequence when they begin teaching something that is new to them.

And Modeling Instruction definitely qualifies as something knew. It is not yet a part of standard teacher preparation programs at the vast majority of colleges and universities in this country. It is not surprising, therefore that we (teachers) focus on our own performance and evaluate it procedurally as if it could be broken down into steps and solved like a mathematics or physics problem. Moreover, once we get comfortable with the procedures that we have identified as modeling, we turn our focus to the task, making our performance of these procedures as technically competent as it can be.

It is not until we take that final step of turning our gaze away from ourselves and our craft, and toward our students, that we are really engaging in Modeling Instruction. Modeling done well is not about the performance that the teacher turns in on a day-to-day basis—it is about the mastery that the students are able to achieve of the set of models they are constructing and using.

What follows is a list of suggestions drawn from this study that may help teachers zoom out and focus on students.

- Design tasks for small group work that focus on probing the problem space rather than tasks that require the use of a certain formula or produce a particular type of answer. Do less of whiteboarding for Going Over Homework and more of whiteboarding for Practicing With The Model. This means that everyone in the class may be doing the same problem. Use board meetings rather than formal whiteboard presentations to share these exercises with the whole group. They are a more effective use of time.

- Expect your students to lead in board meetings. Hand over the floor to them so that they can take turns as leader and interlocutor. Encourage them to talk to their classmates—not to you. Follow their lead. Prompt rather than grill. Probe the CS-SR interface—the boundary between saying and seeing. If students are zoomed in on the computation process, help them zoom out by redirecting their gaze to the problem context and physical situation that structure their problem space. And if an important question is on the table, such as when a model applies, do not let them off the hook by answering it yourself. Make them find the answer themselves, even if you have to come back to it later.
- Encourage the students to examine the conceptual system that they bring to their problem space. If they can see that elements of this system are missing from their whiteboards, *they* should add them.
- In reviewing what a group of students has whiteboarded with the whole class, ask them if it contains all the necessary conceptual elements to build a model of the problem at hand. If not, do the students possess the necessary missing conceptual elements and can they activate them, bring them into their conceptual system and connect them to existing structures in such a way that they are useful for solving problems? If not, are there students in the class who can help them with this process? Encourage them to identify and use the resources that their classmates possess rather than providing them yourself.
- Attend to students as individuals as well as in groups. Learn to watch and listen to what students who are listening to the presentations of others say and do. Are they engaged? Are they perplexed? What are they taking from what is being said? This is hard to do unless we let someone else have the floor. When we are on deck, we do not have the attention to spare to focus on individual responses to the discourse. We need to practice not taking charge of the conversation.
- Break the habit of soliciting or listening for particular words, phrases or answers —particularly when these answer are just a two or three words long. Sometimes when teachers hear one or more students answer their question with the ‘magic word’ (or words) they are listening for, they take it as a signal that they can move on because the students “get it.” Remember to check on what it is that the student “gets” and consider checking with the rest of the class to see if they are following this student’s line of reasoning.
- Listen for the kinds of things that students think are important enough to question. Where are these things in their concept system? Are they from the CS or the SR? Is the student zoomed in or zoomed out? Change their focal plane and see what happens. Listen for potential gaps in their model that are betrayed by the questions they ask. We must take time to get to know our students—what they value, what they think—what the telltale signs are that reveal when they are bluffing or guessing.
- Ask your students the kinds of questions you would ask yourself if you were trying to set up a problem. Critique them as you would critique yourself. They will learn to critique themselves and others by imitating you.
- Do not let them off the hook by answering important questions for them—and do not move on to a new idea if important questions are not answered to everyone’s satisfaction. Make them arrive at the answer themselves—answers they can

justify—not just answers they have guessed right. Make sure they are convinced and can convince each other that they are reasoning correctly about a situation. Then take the vital step of checking with other students to see if they are convinced. And do not take yes for an answer. Make them articulate what they understand in their own words and listen to see if there are any important elements missing from what they say. Make sure they can zoom in and zoom out without their model falling apart.

The whiteboard is not just a tool—it is a medium for communication, for joint attention and cognitive (as well as social) interaction. Whiteboarding is not simply telling what you know, nor is it merely "show and tell." It is collaborators interacting at their CS-SR interface to show themselves and one another what they think. Until they can write it down and make a convincing case of their reasoning to their peers, their private mental models remain poorly structured. Whiteboards can afford the necessary platform for representation of the structure of a problem space and help students see the relationships between elements within the conceptual system that they bring to this problem space. Whiteboarding can also facilitate sharing of information and conversion of that information to knowledge that is held in common by members of the group.