Dear FIG Student,

Welcome to Teaching Science: Mix it Up! My name is Liz, and I’ll be your FA this fall, leading your college connections class where, along with Randy Sullivan, we will make connections between the two classes you all will take as a FIG - general chemistry lecture and general chemistry lab - introduce you to the academic resources available at the UO, and help you transition to college life. Essentially, want to equip you all with the tools necessary to succeed academically and socially here at the UO.

In Teaching Science you will explore and connect the scientific principles you’ll learn in lecture with the hands-on lab, including atomic structure and trends, stoichiometry, and thermochemistry. In the College Connections class, one of your assignments will be to design a chemistry demonstration in pairs and present it to your fellow FIG students and an elementary school class as part of a “demo show”, giving you hands on experience using a practical demonstration to teach scientific principles – the essence of Teaching Science! This summer, you have some required reading. Please read the journal article following this letter on chemistry demonstrations and student learning, and come prepared to critique a demo during our Week 1 class meeting based on what the article says about how students learn or don’t learn from demos.

I’m going into my senior year as a Biology and Spanish major. After graduation, I want to apply to Teach for America. My hometown is Salem, Oregon, and I absolutely love the Willamette Valley area! Beyond being an FA, I’m involved in UO’s debate team – this summer I will be working at UO’s own debate camp, the Oregon Debate Institute, and I’ll be serving my second term as Team President. I also coach high school debate out in Springfield, OR. I love being involved on campus and off, so if anyone’s looking for a club to join or activities to be a part of, I can help point you in the right direction! When I get a weekend off, I like to spend it enjoying the beautiful natural scenery around Eugene or curled up with a cup of coffee in one of my favorite study spots if it’s raining too hard.

Our College Connections instructor is Randy Sullivan. Randy performs lecture demonstrations for all of the undergraduate chemistry courses, so he will be doing demos for you in your CH 221 and CH 227 courses, as well as in this College Connections course. Randy has been a native Oregonian for 17 years, but he originally hails from Texas. He earned his BS and MS at the University of North Texas. He loves to read about European history, play Dungeons and Dragons and arguably has the most fun job on campus!

I’m so excited to meet you all, and get to know you over fall term. Randy and I will see
you at the **Week of Welcome meeting held on Friday, September 21 in Columbia 150 at 11:00 am** where we will introduce ourselves, you can get to know your fellow FIG students, and see where your FIG classes will be held. **We will be attending the University convocation together as a FIG on Sunday, September 23.** This will be a great opportunity to kick off your academic year at the UO, so mark your calendars! Please also shoot me an email with some info about yourself – what you like to do, what classes you’re taking, and a little general info about yourself – before we meet in September. If you have any further questions about the FIG, the courses, Randy, myself, or the UO, feel free to send either one of us an email.

We’re looking forward to meeting you and working with you this fall!

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Why May Students Fail to Learn from Demonstrations? 
A Social Practice Perspective on Learning in Physics

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Abstract: This study was designed to find out why students may fail to learn from teacher demonstrations. In the context of an interpretive study in an Australian senior-year physics course, data were collected to understand the constraints that mediated learning about rotational motion. Over a period of 6 weeks, we gathered observational data, videotapes of classroom transactions, interviews with students and the teacher, and students’ notebooks. Our analysis revealed six dimensions that may have prevented students from learning what the teacher had intended. These dimensions included (a) students’ lack of a theoretical framework to separate signals—the phenomena—from noise, (b) interference of discourses learned in other contexts of the physics course, (c) interference from other demonstrations and images that had some surface resemblance, (d) students’ problems in piecing together coherent representational frameworks from the information given, (e) low salience of knowledge related to demonstrations on tests, and (f) lack of opportunities for students to test their descriptions and explanations. A set of recommendations is presented designed to facilitate teachers in changing their perspective on demonstrations and their associated practices for improving student learning. The recommendations are embedded in a framework that allows teacher reflection and action research. J Res Sci Teach 34: 509–533, 1997.

Introduction

Mr. Sparks picks up a bicycle wheel and sits down on his turning stool, which is hidden from view for all but the students in the first row. (Figure 1 depicts the episode and its content from a scientific perspective.) He invites students to observe. “So, all right now, there are a few other ideas we can put together with this. I got the bicycle wheel; some kind child donated it.
Now just watch very carefully. At least you can see the part you need to see: that is, the top of my body and the wheel. Right, watch carefully."

He rapidly spins the wheel with its axis vertical—that is, parallel to the axis of the turning stool. This is associated with an almost unnoticeable opposite spin in his body. Mr. Sparks comments, “This chair isn’t very good. I’ll try that again.”

This time, the chair makes about a one-eighth turn. “Did you just see it? Look again, look at my body mainly. What was my angular momentum just now? Zero. I’m isolated, sitting in this awkward-looking position. When I spin it, what do you notice?”

Norm calls out, “Opposite to the wheel.”

“Yes I’m going the opposite way to the wheel. When we are looking at these vectors, to start with, $L$ was zero, wasn’t it? That’s my angular momentum. It’s made up of two things: my angular momentum and the wheel’s both 0, to kick off with.”

Mr. Sparks walks to the chalkboard and writes: $L = 0 = L_{\text{teacher}} + L_{\text{wheel}}$. He continues. “The angular momentum is the vector and has direction. This is how we measure the direction of angular momentum. You see, when I spin that, when it spins, if I put my fingers in the direction of the spin, my thumb comes out the axle.” He curls the fingers of his right hand in the direction of the turning wheel while sticking out his thumb. “So that was taken as a vector representing angular momentum. That vector, it’s a radial vector. If I spin it that way, that’s the vector; if I spin it reverse, my fingers that way, the vector would be going down.” He repeats the curling of the hand with the thumb pointing along the bicycle wheel’s axis every time he talks about direction and vector. “It’s not a real vector like linear ones. It’s called a radial vector or an axial vector. It’s the direction of the axis using a right-hand grip rule. All right? Now, when I’m down here and spin it that way, it now has a value of $L$ vector pointing upwards of so much

Figure 1. From a canonical perspective, the teacher rotates in the direction opposite to the bicycle wheel so that the angular momentum of the entire system (tire, teacher/chair) is conserved (a). This can be represented by means of vectors (b). The vectors representing the tire and the teacher/stool are equal in magnitude but opposite in direction. If the tire is held with its axis of rotation perpendicular to the axis of the stool, the teacher/stool will not rotate (c).
magnitude. How long that arrow is depends upon—I’d have to do an ‘I-omega squared’ for the wheel. My body went the other way, didn’t it? How did I spin the wheel? The wheel was going that way, my body rotated the other way, my body had a vector thus; so it was a positive vector, a positive angular momentum, so my body would be that [gestures with thumb upward]. So this takes on positive; my body took on negative [angular momentum]. When I stop it [he stops the wheel], the reverse happens doesn’t it?"

At this point, Mr. Sparks steps on the chair. “So, all right, have a look at this one. I’m going to spin it this way and nothing will happen, because there’s no way I’m going to let my body rotate.”

He spins the wheel with the axis at a right angle to the axis of the stool. “Hang on, I’ve just got to turn that up,” and turns the wheel’s axis 90°. The stool rotated about a quarter-turn. “Did you see that? I’m going to stop it.” He stops the wheel, and the stool returns into its original position. He explains, “See what happened to me? This was going in that way, rotating that way, vector upwards. When I stopped it, my body took it on and my body took on that angular momentum, see.”

After repeating the demonstration twice, he is about to move to the next demonstration, when Andy calls out a question. “When you turn this [wheel] over, will that do it in the opposite direction, which will also help you stop? When you turn that over 180 degrees?”

Mr. Sparks responds, “That’s what I want you to think about; why, when I turn it over, did I reverse? Now I should keep spinning if it wasn’t for the darned friction in this chair.”

Andy is not satisfied. “But now the chair’s—the wheel is pulling a force which is stopping you if you turn it over 180 degrees.”

Mr. Sparks replies, “I’m not even mentioning forces here. I’m an isolated system, by turning it over; at all times, all I know is, big L for this whole system is zero.”

Andy persists. “Just turn it 90 degrees.” Andy goes on further to ask whether if Mr. Sparks had the same qualities as the bicycle wheel, would he spin at the same speed?

Mr. Sparks says, “What’s that? Comparably, but the other way, yes,” and moves on to demonstrate another example of the conservation of angular momentum.

This was a typical example for the many demonstrations Mr. Sparks presented to his students during this and other lessons on angular momentum. It was typical in that he was talking most of the time. There were few interactions with students, especially of the type we have seen here, where a student persisted. In fact, during the 4-week period, we observed only two such interactions. At the same time, the researchers in the classroom regarded the numerous demonstrations as skillfully performed and a rich source of applications of angular momentum. It was surprising, then, that in our posttest, which included interviews with 10 students, when we demonstrated the very same phenomenon using a low-friction turntable rather than a stool, only 4 students could show the direction of the vector representing angular momentum; of these, 3 also knew how to indicate angular velocity by means of an arrow (vector). Only four students drew on the conservation of angular momentum as a resource to explain why there was little or no movement when the wheel’s and the turn table’s axes were (nearly) perpendicular, but there was a considerable rotation of the turntable in a direction opposite to that of the wheel when the axes were parallel.

We observed similar problems with many other demonstrations. Mr. Sparks liked to develop demonstrations and spent much time in developing and building demonstrations that he thought would illustrate the canonical principles that he wanted students to learn. In some sense, he was earnestly trying to provide a rich and varied experience for his students. Yet, most students in this classroom failed to come to an understanding of many of his demonstrations and the canonical physics associated with them. Although the demonstrations were technically well prepared, and although Mr. Sparks talked about the major concepts involved, students often ap-
peared to learn little from this aspect of the course. This raises the question of why these students learned so little from Mr. Sparks’s demonstrations. The purpose of this study was to analyze why students failed to understand the demonstration from a canonical physics perspective. This is not an exercise in criticizing a teacher, but an attempt to understand the problems in a widespread teacher practice and to arrive at a set of recommendations for change that are at once intelligible and feasible from a classroom teacher’s perspective.

Observations and Demonstrations

Science teachers often employ demonstrations to show scientific principles in action. However, there may be some problems with this practice. It is widely accepted that all observation is interpretation (Feyerabend, 1976; Hanson, 1965; Hodson, 1992; Rorty, 1989). Because interpretation arises from the interplay of existing understandings (prior experience) and the world, what one observes depends on what one already knows. This means that students who do not yet know the relevant scientific principles will be unlikely to see just what the demonstration is to show, for the very principles that are to be exhibited are prerequisite to seeing the intended phenomenon. That is, students “perceive science demonstrations from a perspective that differs from that of teachers and scientists” (Shepardson, Moje, & Kennard-McLelland, 1994, p. 244), and their ability to relate the scientific understanding to the phenomenon observed is constrained (Schollum & Osborne, 1985).

Most research regarding learning assumes the existence of an inherently structured world with clearly identifiable phenomena. Phenomenologists and pragmatists consider this assumption to be problematic and even untenable (Heidegger, 1977; Quine, 1992). It has been shown that seeing the world around us with specific objects and properties is not a self-evident process, and that students structure the world differently from their teachers and the community they represent (Roth, 1995). To understand students’ talk and action in science classes, it is therefore helpful to model the ontology of the lived world as ambiguous and undetermined before the act of interpretation. Objects become the things they are, with their specific attributes, through acts of interpretation. Specific interpretations arise from the interaction of prejudice (Heidegger’s term) and world, with prejudice arising from and building through past experience. (Following phenomenological practice, we frequently use world without in/definite article. This use corresponds to and reflects the assumption of the ambiguous ontology of worldly things.) That is, the horizon of an interpretation is predetermined through experience and the practical competence of the individual. Recent neurophysiological and neuropsychological evidence supports this contention; all signals, e.g., from the eye to the brain are filtered and shaped by signals from the brain to the eye (Clancey, 1993; Varela, Thompson, & Rosch, 1993).

There are other descriptions of knowing and learning that question traditional conceptions of demonstrations. Etymologically, the word demonstration derives from the Latin monstrare, meaning to show or point out, and de is a reinforcing device. To be able to recognize that which is pointed out, a person must be able to see. But this requires that prior mastery of the theoretical framework—that is, the discourse that the demonstration is intended to develop. A new relationship between language and visibility of phenomena has been suggested by recent work in the history and philosophy of science. Accordingly, discourses and world are mutually constitutive of each other (Gooding, 1992; Rorty, 1989). Material practices (manipulating objects or artifacts) and discursive practices (descriptions, talk, explanations) coevolve and reify each other. There is historical evidence that initially, Galileo could not see motion on the inclined plane as we see it today. His understanding of velocity and the linear relationship between instantaneous velocity and time came about only after he had changed his notion of velocita (average
velocity) to the present-day conception of instantaneous velocity (Drake, 1978). In his days, two accepted “pieces of knowledge” mediated his seeing and understanding. First, ratios could only exist between like things, not of two unequal things (e.g., distance and time) as is required for the modern notion of velocity; and second, there was the impossibility of an instantaneous velocity (something measured over a zero time interval). Without a discourse about velocity, there was no phenomenon; and without the phenomenon, a discourse was of little use.

**Research Design**

This article is part of a larger interpretive study concerning teaching and learning of rotational motion. We began the present analyses with the assumption that reasoning is observable in the form of socially structured and embodied activity (Garfinkel, 1991; Heidegger, 1977; Suchman & Trigg, 1993). We considered videotapes and transcripts to be natural protocols of students’ efforts to make sense of events, structure their physical and social environment, or communicate with the teacher. These protocols provided us with opportunities for construing the conversational and cognitive work done.

**Participants**

We conducted our investigation in a Year 12 physics class of a suburban state high school in a large Australian city. All students in this course had also studied a Year 11 physics course, most with the same teacher. Most of the students were university bound. In this school, students frequently select the subject because it is an entrance requirement for many science- and technology-related programs at the local colleges and universities. The physics class we studied was 1 of 2 in the school. It consisted of 17 boys and 7 girls and was taught by Mr. Sparks. Mr. Sparks has a graduate degree in science education, has published in science teacher journals, and presented workshops at many conferences. He is recognized by his peers as a very competent teacher with great skills in preparing new and standard demonstrations and in interfacing computers with student laboratory experiments for data collection and analysis purposes.

**Curriculum**

Physics is taught in three 70-min lessons per week, so that the unit on rotational motion was covered in 4 weeks. Mr. Sparks used a variety of teaching techniques. First, he used lectures during which he presented students mostly with the mathematical aspects of rotational motion. Second, he used demonstrations to show, from his perspective, relevant concepts. Third, through laboratory activities he intended to help students understand both qualitative and quantitative aspects of rotational motion. Finally, students did word problems, predominantly as homework assignments and when there was spare class time. Mr. Sparks expected students to do the homework, but did not check whether students actually did the activities. He also expected students to ask him or their peers for help when they did not understand or could not do problems, but did little to ensure that students actually constructed meaningful understandings in the course of the unit. At the end of this unit, two tests assisted him in assessing students with respect to rotational motion. In a process test, students were to demonstrate their skill in interpreting data and make both qualitative and quantitative assessment regarding the moment of inertia of various objects. The second test consisted of traditional word problems and a few short-answer questions.

During the Year 11 physics course, students had been introduced to circular motion in non-
vectorial form, including the notions of angular velocity ($\omega$), centripetal force ($F = m\omega^2R$), and the relationship between velocity and angular velocity for an object in a circular orbit ($v = \omega R$). Our pretest and the related interviews with 10 students indicated that students’ discourse related to circular motion was piecemeal—consistent with diSessa’s (1993) observation of “knowledge in pieces”—and mostly related to the rote application of formulas (Roth, Lucas, & McRobbie, 1996). The topics of the unit we observed were angular velocity, angular momentum, and angular acceleration and their vectorial nature; moment of inertia, specifically those of hollow and solid cylinders, solid spheres, and barlike objects; the parallel axis theorem; the period of a physical pendulum; and the law of conservation of angular momentum.

Mr. Sparks’ lectures generally were formula-driven. He often began by writing a formula on the chalkboard, showed its similarity with an equivalent equation describing linear motion, and then focused on the relationship of the quantities in the equation. For example, to teach the conservation of angular momentum, he stated that this quantity was conserved, and then concentrated on the relationship between angular momentum, moment of inertia, and angular velocity ($L = I\omega$). He drew the right-hand side of the equation with an oversized $I$ and minuscule $\omega$, or vice versa. That is, he tried to help students understand the inverse relationship of moment of inertia and angular velocity, but never ascertained whether they had constructed a meaningful understanding of angular momentum, angular velocity, or moment of inertia. During such lectures, students generally noted the equations Mr. Sparks had written on the chalkboard. Consistent with the lectures, the students’ independent work mainly consisted of traditional word problems.

Mr. Sparks performed many demonstrations, often classical, in the area of rotational motion. Among these were scenarios where he walked on a fence as if it were a tightrope using a long iron bar; he modeled the increasing spin of ice dancers on a rotating stool, with bricks in his hands; he asked students to turn a quickly spinning flywheel (a nearly impossible task); and he suspended a quickly spinning bicycle wheel on one side of its axis only, letting students wonder why it did not drop. He had a virtually unlimited stock of demonstrations, and the researchers ascertained that most were well prepared and executed.

Student laboratory investigations included the determination of the center of mass of irregular but flat objects (qualitative); the motion of objects when pushed away from the center of mass (qualitative); microcomputer-based laboratory investigation of the acceleration of a circular object with changing moment of inertia (quantitative); a qualitative investigation of moments of inertia of spherical, cylindrical, and sliding objects; verification of equations for spheres, solid cylinders, and hollow cylinders rolling on an incline (quantitative); and determination of moment of inertia by geometrical and experimental (through period of pendulum equation) means (quantitative). According to students, the number of investigations was much higher during this unit than during any other in their 2 years of physics.

Data Sources

Prior to the primary data collection effort, the research team (consisting of the four authors) spent 1 week in the class for observation. These observations and results of several instruments related to other aspects of the larger study were used to identify ten students whose learning and views on a variety of issues we wanted to follow more closely. The 10 students we selected represented (a) the spectrum of achievement levels, (b) three clusters of views about the learning environment (cf. McRobbie, Roth, & Lucas, in press), and (c) different epistemological and ontological commitments (cf. Lucas, McRobbie, & Roth, 1996).

We recorded the entire 4-week unit using three videocameras and a cassette recorder. The
cameras focused on three student groups including 9 of the 10 selected students. Mr. Sparks wore a wireless remote microphone whose signal was fed into the cassette recorder. Three researchers kept observational and theoretical field notes which were also entered into the database. All videotapes and audiotapes were transcribed within hours to a few days after they were recorded.

The 10 students were interviewed on a minimum of five occasions. The topics of these interviews included (a) students’ understanding of rotational motion before the unit; (b) students’ understanding of rotational motion after the unit; (c) students’ views of the learning environment; (d) students’ views of epistemology, ontology, and the nature of science; and (e) students’ views of teaching, learning, and understanding. During the interviews, we also played back video clips of teacher demonstrations and lectures (including the demonstration in the Introduction to this article) or of student investigations. These stimulated recall sessions were designed to deepen our emerging understandings of teaching and learning, and to test emerging working hypotheses. Each interview lasted between 40 and 70 min. All interviews were recorded and transcribed within a few days of their recording. (Two authors and four research secretaries ascertained that the transcriptions were up to date and therefore available to the ongoing meetings during which we decided on further data collection.) The interviews were open-ended and unstructured, but loosely followed the topics of the written instruments.

Mr. Sparks was formally interviewed on six occasions following the same interview schedule as the students. Further, the interviews included questions as to his goals with each lesson and his rationale for each lesson component. In addition, we debriefed with the teacher after each lesson when specific artifacts and chalkboard inscriptions were still available as references. The interviews—which lasted between 60 min and 2 hr—and the daily debriefing sessions—which lasted from 15 to 30 min—were recorded and subsequently transcribed.

We usually began the interviews with participants’ responses to one of a series of questionnaires, and then asked students to relate these responses to the enacted curriculum, teaching techniques, and so forth. Participants completed a constructivist learning environment scale (Taylor, Dawson, & Fraser, 1995), a nature of science survey (selected items from VOSS [Aikenhead, Ryan, & Fleming, 1989]), a science laboratory environment inventory (SLEI) (McRobbie & Fraser, 1993), an instrument assessing students’ preunit understandings of rotational motion based on items used in previous research (Gardner, 1984; Gunstone, 1984), and an instrument assessing participants’ postunit understandings. Further, we included the teacher’s own tests in our database. Mr. Sparks completed the same inventories (the learning environment inventories were rewritten as a teacher form), but was asked to predict students’ answers on instruments designed to assess their understandings.

Central to the investigation was the posttest question that was virtually identical to one of Mr. Sparks’ demonstrations (Figure 2). We asked students first to predict what would happen, then observe, and finally explain their observation. While the students responded to our questions, we asked Mr. Sparks to indicate on the same test form how he thought students would answer and to estimate the number and type of students giving the answers. Other posttest items (not shown here) were designed to probe students’ understanding of linear velocity, linear acceleration, forces, angular velocity, angular momentum, and the moment of inertia of bodies in circular motion.

Data Interpretation

On the basis of our field notes, daily viewing of videotapes, and daily reading of interviews, we generated questions and tentative assertions. We returned to the classroom, interviews, and
existing database to construct answers to our questions, or to dis/confirm our working hypotheses. For example, the earliest trace for the concerns raised in the present article appeared in the following field note. (All longer quotations are coded according to the source document in our files.)

> Sometimes even the teacher can’t do what the experiment is supposed to do. Mr. Sparks can’t make the things do what they are supposed to be doing. For example, in the little demonstration with the beachball, that didn’t turn out the way it was supposed to. Teachers frequently do experiments/demonstrations that aren’t going the way they are supposed to, failing to reveal the “structure” of nature. [0731MR]

Field notes such as this one became topics for our team discussions and guided our subsequent data collection. Based on such early field notes, we used videotapes of demonstrations during interviews to find out more about Mr. Sparks’ intentions and students’ understandings of demonstrations through stimulated recall. A later field note shows the stand of our investigation about one of the dimensions that became important in our explanation:

> In this classroom, there is a lack of opportunities for the students to check whether their own talk about the phenomena was shared with others, was viable, was fruitful, or whether it needed to be changed. [0818MR]

On the same day, we noted the requirements for further data collection.

> Use stimulated recall with the [bicycle] episode and selected students? Interview students about: “How do you know what you were supposed to see?”, “Mr. Sparks’ explanation of the phenomenon,” “What would you have needed to understand?”, “Why did you not pursue understanding?” Use footage from 0804V3 between 10:29–10:40. [0818MR]

In the same way, we designed the collection of other data that would help us to understand our initial question of why students may fail to learn from demonstrations. As the study progressed, we evolved internally consistent descriptions and explanations for our phenomenon of teacher demonstrations. In the process of our interpretive work as a team, we developed shared ways of viewing the classroom, videotapes, transcripts, and other artifacts. Initially tentative construals of events, utterances, and people’s explanations became reifiable within the life world constituted by the physics class and our records of it. An important aspect of the interpretive process were daily formal analyses, debriefings, and informal conversations during 7 weeks of intense collaboration. Our interactions were important because of our different background experiences and subject matter expertise. Those of us who had previously taught physics at high school or university levels shared with the teacher tacit knowledge required for understanding that was not self-evident to the physics neophyte in our team. Through the physics neophyte on our team, we began to see the events in this class in the way they must have looked to students. In addition, the members of our team brought to this study different conceptions of knowing and learning. Our interactions therefore helped us consider alternate interpretations within our group. Of additional importance were seminars where we presented draft analyses of our emerging and necessarily tentative understandings to our colleagues. Our understandings evolved when we tried to (a) communicate initially fuzzy ideas and (b) take into account the audience’s questions and criticisms. (We attempted to include Mr. Sparks’ reactions and comments. Whereas he agreed in most general terms that we had addressed some problems of
Research Findings

The present analysis is part of a larger study designed to understand learning and teaching in a traditional physics classroom—that is, in a classroom where the teacher viewed teaching and learning as the transfer of information. Here we are interested in understanding what students learn from teacher demonstrations and what factors may mediate the learning process. We begin this analysis with an assessment of the situation. The questions to be answered in the first section are, What are the teacher’s goals in this demonstration? and What did students learn? Our findings then provide the context for an answer to our question, What are the mediating factors that may have impeded learning from Mr. Sparks’ demonstrations?

Teacher’s View of Demonstrations and Student Understanding

Purpose of Teacher Demonstrations. Mr. Sparks described teacher demonstrations in classical ways and in terms of a discourse rather characteristic for traditional teaching practice. We provide here a description of Mr. Sparks’s views to contextualize our later recommendations concerning how he might modify his practice of demonstrating to allow for greater learning.

Mr. Sparks prepared demonstrations because, as he said, they keep his own interest up, which is the major motivation for what he is doing in the classroom. He likes to prepare spectacular demonstrations (and computer hardware and software), and does not mind spending a lot of time in and out of school doing so:

I am always looking for demonstrations, experiments that are interesting. I build a lot of stuff and make a lot of stuff and I just tie them in as I go. For example, in the holidays, I usually get into the university and look up the Physics Teacher and look for new ideas and then somehow during the year, run these past the kids. (Mr. Sparks, 0725A2)

He argued that these demonstrations assist students in forming mental images which help them to remember even years after they have seen one of his demonstrations.

I think that average and good students should, a week later, be able to close their eyes and mentally run through what they saw happen and relate it to a question asked and then come up with the answer by seeing in their mind what was demonstrated. (Mr. Sparks, 0824V1)

He suggested that nature has an inherent structure which has its origin in the plans of a divine being. This order reveals itself, for the well-intentioned student, through careful observation of phenomena. To facilitate this process, he prepares different demonstrations that show the same idea but in different contexts.

At the time of our posttest, we asked Mr. Sparks what he thought students should be able to do after his demonstration (which we represented in the opening vignette). Up to this time, he had shown several demonstrations to help students understand the dynamics of rotational mo-
tion. Mr. Sparks suggested that the central purpose of this demonstration (Figure 1) was to facilitate understanding of the conservation of momentum:

That they could state clearly what they observed as correct facts. That when I rotated the wheel this way, my body spun that way, and they could quote that this illustrated the conservation of angular momentum. That I had nothing to start with, and afterwards the wheel had so much this way and my body had so much the other way, adding up to zero. (Mr. Sparks, 0824V1)

Because Mr. Sparks made frequent references to the vector nature of angular momentum and the direction of this vector, we wanted to know what he expected students to have learned about vector descriptions. Mr. Sparks suggested that students should be able to (a) measure angular momentum as a vector; (b) find its direction by using the right-hand rule; (c) know it as an axial vector; (d) put their hand next to a spinning wheel and indicate with their thumb the direction along an axle that would represent a vector line showing the angular momentum of the wheel; (e) indicate the magnitude of angular momentum; and (f) explain, and draw a pencil diagram of, the idea of angular momentum. From Mr. Sparks's (classical) perspective, knowledge is a modular kit. Words (concepts) have meaning and refer to ontologically real objects. Looking at real objects and events allows a direct view of the concepts (the ideas), the labels of which are provided by the teacher. He assumed that “intelligent” individuals can connect the knowledge of these modular and separate pieces, see the identical underlying structure, and transfer their knowledge onto another context. Thus, he frequently did not answer a student question, but insisted that the student “think up why that happens.”

Mr. Sparks was quite confident that his students had learned from the demonstration:

I would say two-thirds of the class, I would feel, have had a reasonable understanding of what happened . . . and one-third, I would say, when really thinking about it, when probed, would come up with a fairly reasonable set of answers. (Mr. Sparks, 0824V1)

He expected that “most” students would explain our posttest questions in canonical terms. For example, he suggested that students would explain the absence of motion when the wheel’s angular momentum was perpendicular to the table’s axis (Figure 2A) by making reference to the orthogonal (horizontal versus vertical) position of axis and angular momentum; a “few very good” students would include a reference to the law of conservation of momentum. In the second situation, where the angular momentum of the wheel and the person’s axis of rotation are parallel, he expected “most” students to invoke the law of conservation of angular momentum and include the statement, “Original angular momentum equals zero and after the change to Position B, the man moved with the opposite angular momentum to the wheel.” He expected “some” students to identify the direction of angular momentum consistent with scientific canon.

**Students’ Explanations and Use of Representations.** As we observed this classroom, we formulated an assertion stating that students learned very little from the many demonstrations performed by Mr. Sparks. To test this assertion, we selected a posttest task that was very similar to one of the demonstrations, differing only in the object that permitted the person to spin: Mr. Sparks sat on a rotating stool (Figure 1), whereas the person stood on a rotating table during the posttest demonstration (Figure 2). The drawings accompanying the test question had high epistemic fidelity: The representations of objects, direction of motion, verbal descriptions
of motion and objects, and perspectives were as students would see the presentations from their seats.

An explanation within canonical physics of the situation in Figure 2 runs as follows. The rotating table (and its load) with an axis in the vertical direction ($z$) has an angular momentum of zero, $L_{\text{table}} = 0$. As long as the wheel’s axis of rotation, and with it its angular momentum $L_{\text{wheel}}$, is perpendicular to $L_{\text{table}}$, the table will remain at rest because $L_{z,\text{wheel}} = 0$. If the wheel is turned so that its angular momentum has a component parallel to the vertical axis, the table will begin to rotate in the opposite direction so that angular momentum is conserved, that is, $L_z = L_{z,\text{wheel}} + L_{z,\text{table}} = 0$. Here, the direction of the angular momentum is given by the normal (perpendicular) vector to the plane of motion.

On our posttest, only three students indicated the canonically correct direction of the angular momentum vector. In two of these cases, the direction was inconsistent with that of angular velocity, although students invoked the relationship $\mathbf{L} = I\mathbf{\omega}$, according to which angular velocity and angular momentum have to point in the same direction ($I$ is a scalar). Eight students used arrows either parallel to the linear velocity vector or curved and parallel to the tra-

Figure 2. Posttest and canonical explanations of the demonstration involving the bicycle wheel. No movement should be observed when the wheel’s axis is orthogonal to that of the table (A), but a counterclockwise movement should occur when the two axes are parallel (B). If the wheel in (A) has an angular momentum with a small component in vertical direction, that is, if $L_{\text{wheel}}$ is not perfectly orthogonal to the table’s axis, a small angular velocity will be observed.
jectory. Twelve students did not respond at all, or indicated “Don’t know.” Even Sean, one of the top four students with “very high achievement” in this class, did not infer the direction of the angular momentum vector:

Angular velocity. It’s like the momentum. Not sure about the direction of it. Mr. Sparks hasn’t told us yet or I probably didn’t think or couldn’t remember it. I wasn’t sure what the actual direction was that the arrow represented so . . . Well I obviously had an idea on vectors, and they have magnitude and direction. I couldn’t recall the direction, so I just gave the magnitude value. (Sean, 0823V1)

When asked to explain why the person on the low-friction table would spin when the wheel was turned as indicated, only four students provided canonical explanations invoking the law of conservation of angular momentum. Three students provided explanations in which the direction of the table’s and the wheel’s axis was the central feature. Seven students explained by drawing on forces and torques or action–reaction systems. For example:

Because it is a closed system. The force of the wheel caused his body to turn. Every action has an equal and opposite reaction. Therefore, his body turned in the opposite direction to the spinning wheel. (Allan, posttest)

Like many of his peers, Jon brought his prior understandings from Newtonian mechanics into play for interpreting what he saw:

Instead of talking of the momentum, I was talking about the forces and direction, and so I think I was talking about the forces activating the wheel, like friction and stuff like that instead of actually momentum. (Jon, 0823V1)

Nine students suggested that total angular momentum changes (although the system was closed from a canonical perspective). Ten students provided no explanation at all.

From the data presented here, we see Mr. Sparks as a well-intentioned teacher with a conservative and information-transmission view of learning and teaching. He presented a classical demonstration couched in canonical discourse; from his perspective, he had provided all the requisite knowledge pieces to construct an understanding of the phenomenon. Students observed, and despite all the explanations, gesturing, and writing on the chalkboard, understood little if anything of the theory that the demonstration was about. In the following section, we provide an account of mediating circumstances that may have interfered with students’ understandings.

Circumstances that May Mediate Student Learning from Demonstrations

In the following, we provide separate descriptions of a number of influences that mediated students’ descriptive and explanatory discourse relative to the demonstration. The influences, however, cannot all be separated entirely, because they interact. For example, students used “force talk” to explain why the stool rotated. At the same time, their force talk also fits with force talk related to precession. We identified a number of influences that mediate what and how students learn from demonstrations. These include: (a) Students have difficulties separating signals from noise—that is, they do not know which aspects of the display they need to focus on to understand the teacher’s accompanying or following theory talk; (b) when students come to see a particular demonstration, they bring with them different discourses that frame their descriptions and explanations, which may be inappropriate for and even interfere with the devel-
opment of a discourse suitable for the situation at hand; (c) other demonstrations students have seen may interfere with their development of a discourse because of superficial similarities in images and discourse; (d) students may not be able to connect the different representations that are implicit in the teacher’s theory talk to other aspects of their knowledge about physical systems; (e) low priority given to constructing and understanding phenomena compared to being able to get the correct results on numerical tasks affects students’ engagement with the demonstrations; and (f) a lack of opportunity exists for students to engage in a discourse about the demonstration to test the appropriateness and suitability for describing, constructing, and explaining phenomena. In the following subsections, we discuss the evidence for each of these mediating influences.

Separating Signals from Noise. For demonstrations to work at all, students need to see what the teacher intends them to see so that his canonical explanation provides a plausible explanation. However, there were frequent situations in which it was not clear to students (or to the observers, for that matter) just what Mr. Sparks wanted the audience to see. Nor was it clear whether what was seen was a signal or noise. (We use the terms signal and noise, which may be considered jargon. However, these terms are appropriate here, because they make crucial distinctions that are at the heart of the problem with which scientists and our students here have to wrestle.) In one situation, for example, Mr. Sparks threw a beachball repeatedly to students and instructed them to throw it back in a certain way. The observers found out only long after the demonstration that it had not shown what Mr. Sparks wanted it to show: An object that experiences a force away from its center of mass will experience both translational and rotational motion. While Mr. Sparks knew that the demonstration did not work, students and experienced observers did not know if they observed a signal or noise.

Students were divided in their observation of the event with the spinning bicycle wheel during the posttest (Figure 2). During the demonstration, the axis of the wheel was not completely horizontal, leading to a slight movement of the person on the turntable. Five students, all high or very high achieving, did not observe any movement—3 had predicted this, while 2 changed between prediction and observation. They considered the wiggles as noise on top of the real signal, no motion. Eighteen students stated that the demonstrator/table system moved—eight of them adding that the movement was “little” or “slight.” These students maintained that the person moved, even when this experiment was contrasted with the situation where the axis of the spinning wheel was parallel to the table’s axis, which gave rise to several complete rotations of the turntable. For these students, the wiggles were the real signal: They had observed significant motion. The uncertainty whether what was observed was to be interpreted as motion or stationary state becomes apparent from Karen’s account of the situation: “The wheel that he was turning, spinning, and that he was fairly much stationary, but he moved slightly and I wasn’t quite sure what the actual movement was” (Karen, 0815V1).

However, during Mr. Sparks’s demonstration, the stool moved only one-eighth of a turn. From the perspective of the uninitiated, it was not clear whether this was actually noise or signal. When he reviewed this demonstration on video, Mr. Sparks was aware of the small size of the signal, but noticed that he had told students about the friction that had slowed him down. In reaction to the test item where the angular momentum of the wheel was perpendicular to the table’s axis, Mr. Sparks suggested that some students may predict a rotation. However, he thought that all students would observe that there was no rotation, and expected students to use an explanation of the type, “The axis of the wheel was horizontal; hence, the man did not spin about a vertical axis.”
We asked students who considered the movement to be insignificant how they could maintain their claim given that so many of their peers had seen the demonstrator move. For example, Jon contrasted the two situations, with the wheel’s axis perpendicular and parallel to the stool’s axis. In the light of the movement with axes parallel, he interpreted the other movement as nonsignificant.

An explanation drawing on students’ inexperience in separating signals from noise or, worse, invoking low ability would not be satisfactory. Developing the competence to separate signals from noise constitutes the daily work of scientists and engineers alike. Such interpretations are impossible to make out of context, for signals of the same order are significant in one, but simply noise in the other context (Bucciarelli, 1994). That is, the ontology of a data point is not absolute but a question of theory. However, here as in many classrooms, demonstrations are designed to help students learn the theory.

Different Discourses. Students bring to the classroom discourses from different out-of-school and in-school contexts. Given that Mr. Sparks’s demonstrations and our posttest were in the context of a physics course, it was not unexpected that students would draw on discursive resources appropriated in this course to explain what they saw during the demonstrations. This was already evident during the demonstration featured in the opening vignette, when Andy invoked forces. During the test situation, seven students explicitly drew on forces, torques, and action–reaction systems. The results on the test suggest that many students inappropriately brought prior understandings from Newtonian mechanics into play to interpret what they saw:

Because if you use the rule, the acceleration and momentum is going through him and it’s perpendicular to where he’s standing. So a force is not applied in this vertical axis, but it is applied in the $X$ axis, so if there’s not force applied in that direction you wouldn’t expect him to move. (Jon, 0823V1)

Jon also invoked Newton’s third law, according to which every action is associated with an equal but opposite reaction, to explain his observation. Such explanations appeared especially appropriate, because there was usually some movement whenever the wheel was accelerated, so that the acceleration of the wheel and the beginning of the person’s motion coincided. Aubrey suggested:

Because it is a closed system. The force of the wheel caused his body to turn. Every action has an equal and opposite reaction. Therefore, his body turned in the opposite direction to the spinning wheel. (Aubrey, posttest)

Others combined discourses from other domains including torques and their magnitude as a function of an angle.

Interference from Other Demonstrations. Students predicted and interpreted events on the basis of prior experience. They used mental images as resources in their predictions, interpretations, and explanations. However, these images and the predictions students derived from them were often inappropriate. For example, both Christina and Karen thought that the person on the frictionless table should turn although the axis of the spinning wheel was perpendicular to that of the table. Asked to explain, they responded:

Partly because I have seen Mr. Sparks and partly because of my own experience with my study chair... Mainly knowledge, that I had seen it before. (Christina, 0815V1)
I thought there would be some movement, because I had seen it before but I couldn’t remember what the movement was. I sort of missed it a little bit because the movement was so slight, so I wasn’t quite sure what was going on, so I couldn’t really explain it. (Karen, 0815V1)

Students’ explanations of the phenomenon were influenced by a number of other demonstrations with surface similarities even if these other demonstrations occurred at a later point in time. One mediating effect was produced by a rather spectacular demonstration during which a spinning bicycle wheel was suspended from one side of its axle without falling to the ground, precessing around the rope which suspended it (Figure 3). On the surface, the situation in Figures 2 and 3 appears to be similar. In both situations, the axle of a bicycle wheel is held parallel to the ground. However, while in Figure 3 the wheel is free to pivot about the point of suspension, which leads to the precession-producing torque, it is fixed for the demonstration depicted in Figure 2. These images and Mr. Sparks’s associated talk provided students with resources to explain the demonstration they had seen earlier and which reappeared during the posttest. Thus, students explained, “The two torsional forces acting on him caused a resulting force which turned him to the left” (Andy); “The torque on the spinning wheel forced the man’s body around with enough force to rotate it” (Allison); “He moved in this direction because of precession” (Brett); and “Precession only occurs when something is rotated around two axes at right angles. The wheel is only rotating around one axis, so no other movement occurs” (Dean). Karen’s explanation was exemplary in one sense. She drew on the teacher’s discourse during the precession demonstration and invoked the existence of two forces: the different directions these forces needed to have relative to each other and the resulting movement of the system.

Students also made explicit reference to a sketch accompanying our Figure 3. Dean had derived his explanation from the teacher’s talk, his perception of the wheel, and the arrows the teacher had drawn on the blackboard as part of his explanation of the precessing bicycle wheel.

I took a lot of it just from what Mr. Sparks said and what he showed us with the three axes joined at right angles, so with the wheel being rotated in front, which is one axis, and

![Figure 3](image_url)

*Figure 3.* Observation: A spinning bicycle wheel suspended on one end of its axis will not fall but precess with an angular velocity \( \Omega \) around the string rope in the direction indicated (a). A canonical explanation of the relation between the precessional frequency \( \Omega \), the torque \( \tau \), and the angular momentum of the bicycle wheel, \( L_{\text{wheel}} \) (b). The directions of each vector is given by the right-hand rule.
then also round the second one. So, the third one is straight up and down, so you’re spinning around that way, so you have to spin one way or the other, and I didn’t know which way. So, yes, from what he said there’s a force somewhere that tends to make it turn around a third axis. (Dean, 0815V3)

Switching Representations. From Mr. Sparks’s perspective, students should have been able to show the direction of angular momentum by means of an arrow in a pencil drawing. Students had been familiarized with the right-hand rule previously and repeatedly: When an object moves in the direction of the curled fingers of the right hand, the thumb points in the direction of the vector that physicists use to represent angular momentum (angular velocity, etc.). Mr. Sparks showed students the direction of the vector using the right-hand rule and wrote the algebraic equation from which the equality of magnitude could be taken ($L_{\text{total}} = L_{\text{wheel}} + L_{\text{eye}}$). Mr. Sparks even said, “This was going in that way, rotating that way. Let me see, vector upwards.” This statement was accompanied by a hand movement showing the direction of the “that way” with his curled fingers, followed by the thumb pointing upward into the air.

However, what Mr. Sparks did not do was to draw on a standard convention for representing vectors—that is, draw arrows whose length are expressions of magnitude and whose orientation indicates the direction of vector quantities. Without the actual drawings, however, “vectors” may be just another term that has no or little meaning; that is, students could not “populate it with their own intentions” (Bakhtin, 1981) and integrate it into their discourse about the situation.

Mr. Sparks’s discourse (see opening vignette) was composed of many elements from different domains. There were descriptions of events happening before the students’ and teacher’s eyes; how to find the direction of the angular momentum vector from the observation (right-hand rule according to which the thumb shows the direction of the vector when the fingers are curled in the direction of the wheel’s motion); a vector as radial rather than a “real” one; intentions normally absent from physics discourse (“There’s no way that I’m going to let my body rotate”); and of the “darned friction in that chair” which interfered with his presentation of the ideal world of physics. These descriptions refer to different worlds. The right-hand rule, then, integrates these worlds. One is constituted by the physical experience that can be observed, measured, and manipulated; another is constituted by the curled fingers that iconically represent the rim of the wheel, fingers pointing in the direction in which the wheel turns. The thumb stands for an object in a different world. It is part of a discourse physicists use to describe and explain phenomena. The thumb stands for a vector, a mathematical quantity which itself can be depicted and represented in a number of ways: some pictorial (arrow of specified length and direction), others in what seems more abstract ways as letters, matrices, and so forth. While these different representations were used exchangeably by the teacher, they constituted different pieces of knowledge for the students. Our posttest and the associated interviews showed that students could not integrate these worlds and their descriptions to an internally consistent framework.

Larger Context of Demonstrations. Many demonstrations were flagged and prefaced with some remark which suggested that students would not be accountable for them on tests. Mr. Sparks wanted to raise interest and wonderment. However, we came to the conclusion that there was a very low priority on understanding from demonstrations. Teacher and students appeared to assume that they remember the events in the case of a test or exam (e.g., “I just watch and soak it all in,” “We just observe what happened”). In such instances, many students diminished their active engagement (e.g., “I mean, you immediately don’t write any notes down or any-
thing; we will just listen to this and have a bit of enjoyment”). As to the importance of demonstrations flagged by Mr. Sparks as being for interest, Rhonda’s response was representative of many we received:

I probably wouldn’t concentrate on that as much, like, I would take notes on what he was doing but then go back to, maybe just use the other stuff if I wanted to know how something worked. Some of it I don’t think I really need to know. (Rhonda, 0815V1)

Students’ notebooks had no reference to any of the demonstrations (“Examples were good; there didn’t seem to be enough behind them; they were just examples of, like, of what it relates to”). If there were any records of students’ note taking during demonstrations, these were always formulas, equations, and calculations that Mr. Sparks noted on the chalkboard, but never descriptions or other forms of representation of what Mr. Sparks showed or the explanations he gave. Problems which required the calculation of missing quantities, and any information that might pertain to these activities, were the few things students always noted. Some students lamented the fact that demonstrations did not lead to better understanding (“We didn’t sort of work out exactly the physics behind what was happening and why it was. I think it would have been better to do that” [Christina, 0815V1].)

*Lack of Opportunities to Test Science Talk.* There were few opportunities for students to test their own understandings. Neither students nor Mr. Sparks appeared to be willing to create such situations—that is, exchanges during which alternative explanations and discourses would have been evident. Mr. Sparks was quite happy to present his demonstrations without interruptions. He repeatedly indicated that his own interests were the primary determinant of what he did in his physics class. As a result, he was so engrossed in demonstrations that he seemed to forget about student learning (“It’s only when sometime down the track I get a wrong answer in a test or I get a wrong comment somewhere that I realize that what was clear to me wasn’t clear to them” [Mr. Sparks, 0824V1]).

When students did ask questions, Mr. Sparks frequently did not take the time to assess what might motivate the student to ask this particular question at this time. (Mr. Sparks was always willing to listen and talk to students after class, or to be called at home by students when they experienced difficulties with their textbook problems.) The exchange with Andy in the introductory episode was typical. Andy provided an alternate description and explanation for the system, including force talk. Mr. Sparks, however, simply shrugged Andy’s comment off: “I am not even mentioning forces.” During our posttest that demonstrated the same phenomenon, nine students (36%) employed force to explain the phenomenon. The episode with Andy illustrates that Mr. Sparks missed an important opportunity himself to learn. His throw-away comment, “I’m not even talking about forces,” was insufficient for students to abandon force talk in the context of this demonstration. It is not farfetched to think that an open discussion would have encouraged more students to join Andy, and therefore provided Mr. Sparks with an opportunity to recognize the extent of this inappropriate discourse.

Students appeared to be content that Mr. Sparks did not ask them to talk about the phenomena. During the 6 weeks we spent in the classroom, there were few moments when students engaged Mr. Sparks, and then they always involved the same few students. Some students also wanted to avoid embarrassment. They did not ask questions because it might be about something they ought to know. They feared Mr. Sparks would interpret such questions as obstinate behavior and become unkind (“I think everyone kind of gets scared that if they ask Mr. Sparks, he is going to yell at them or something, like you sort of think maybe it is something that you’re
supposed to know”). Another student cited specific instances when Mr. Sparks had called on her, and each time she felt it was to embarrass her (“He wanted to embarrass me or something”).

Discussion

The teacher in this study, Mr. Sparks, was typical of many teachers in his transmission view of learning and teaching. He was atypical insofar as he was, in the views of his peers and some observers, very skilled in conducting demonstrations, and that he commanded a large repertoire of demonstrations. He was very well-intentioned, but, bringing to this teaching technique an epistemological stance according to which the world was prestructured and knowledge matched this structure, overestimated what neophytes in physics could see in and learn from these demonstrations. Thus, he told us that students should be able to see conservation of angular momentum in his demonstration, separate noise from real signals, reconstruct the equivalence of signs across representational systems, and so forth. This study showed that Mr. Sparks’s assumptions—and probably those of many other teachers—were unwarranted. Despite his efforts and skills, the students in this class did not understand the demonstration, the conservation of momentum, or the vector representations associated with the various quantities involved.

The intent of this study was not to criticize another teacher. Rather, we attempted to understand how a very common teaching practice—the demonstration of events that are suitable to make scientific discourse intelligible and plausible—under certain circumstances fails to lead to student learning. We were interested in finding out about and understanding these circumstances. In the context of this study, there were six important aspects of the situation that mediated the experience in such a way that student learning of the target concepts did not come about: (a) Without a theory, students had difficulty in separating noise from signal; (b) previously appropriated discourses interfered with the development of a new, situationally appropriate one; (c) the images of other demonstrations and everyday phenomena led students to alternate explanations; (d) students did not construct on their own the equivalence of signs from different representational systems; (e) the overall context was such that many students did not consider demonstrations as something of importance; and (f) students had no opportunities to test whether their descriptions and explanations of the event were viable. The design of our study does not permit us to make inferences as to whether these aspects in fact caused students not to learn, nor does it permit us to say which of the aspects contributed to a larger extent. Our data permit only the hunch that the order of these aspects differs among students.

To learn what the teacher wanted them to learn from a demonstration, students needed to be able to separate signals from noise: Is a wiggle in the body of the experimenter a significant motion or simply an artifact of his preparation? How can students make such a decision? There is evidence from a number of ethnographic studies of scientists that much of their activities concern the differentiation of blotches and wiggles into noise and real signals. Detailed analyses of astronomers’ (Garfinkel, Lynch, & Livingston, 1981), physicists’ (Woolgar, 1990), or biochemists’ (Amann & Knorr-Cetina, 1988; Lynch, 1985) socially and materially situated work show that it consists of constructing real signals from a sea of blips and blotches in rationally accountable and defensible ways. The decision whether, for example, a peak in a spectrum is signal or noise is usually based on theory (e.g., Roth & McGinn, 1997). However, if the theory does not yet exist, scientists may proceed by evolving tentative descriptions and embodied laboratory skills until a local theory emerges. In this way, Faraday separated motions into real and artifactual until he arrived at the first electromagnetic motor (Gooding, 1990). Students who observe demonstrations do not have either the theory—this is what they are to learn from the lesson—or the opportunity (or competence) to make the necessary distinctions. Nor did the stu-
dents in this class have the opportunity to ascertain whether they could come to an agreement as to what they observed. Furthermore, students faced similar problems when they were to learn specific scientific concepts from the laboratory activities Mr. Sparks had asked them to complete. In these laboratory activities, it was virtually impossible to isolate what the real signals were without some notion of the theory to be learned (Roth et al., 1997). Thus, from our posttest data, we know that for the same event that the observations ranged from no motion to significant motion. It is clear that such discrepancies could serve as the topic of a debate in which the signal/noise issue could be raised by the teacher on a metatheoretical (nature of science) level.

A traditional problem of school knowledge is that symbolic systems remain referentially isolated (Kaput, 1988). Students learn to manipulate symbolic structures without referential content and are not provided with opportunities to integrate those symbolic structures that can be used alternatively to describe the same system. Students in this study knew that vectors were quantities with magnitude and direction, had previous experience in writing vector quantities as underlined letters (e.g., $\mathbf{v}$ for velocity), using arrows to represent vectors, and using fingers to represent directions (“right-hand rule” to find the direction of a magnetic field generated by an electric current in a wire loop). However, we have to assume that all this knowledge existed—consistent with diSessa’s (1993) observation—as separate pieces of memorized information. Mr. Sparks had used two of these representational forms, $\mathbf{L}$ and the right-hand rule, but when we asked students to use arrows to indicate the direction of angular momentum, even the highest achieving among them could not do so. Mr. Sparks, though, had behaved in an ordinary way for scientists. Scientific discourse does not referentially isolate, but integrates different forms of representation in situationally appropriate ways (Lemke, in press). Accordingly, an upward vector could be indicated in any of the following four ways shown in Figure 4.

![Figure 4. Four ways to represent a vector pointing up.](image)

Students in this study did not have opportunities to participate in multimodal science talk in the way their teacher, in canonically appropriate ways, practiced it. Consequently, they failed to provide us with the appropriate response that the teacher expected them to give.

The students did not develop the competence to talk about the phenomenon of interest in a way compatible with scientific canon. From the perspective of many of the students, there was no real need to do so. In this classroom, word problems were the main evaluative tool. Students could get these problems right, or at least garner enough partial credit to get a reasonable grade without understanding what the problem was about, or whether it referred to anything at all. Students described strategies for achieving good marks without conceptual understanding. In this context, students had little incentive to see what the demonstration was to show and to develop competence in the associated physics talk (i.e., to develop an understanding). However, even if students tried to make their own frequently alternative descriptions the topic of conversation, Mr. Sparks failed to engage students and simply brushed off any comments that did not fit into his plans. Students therefore had no means or opportunities to assess in which way their talk was inappropriate because, from a language perspective of knowing, competence in talking science requires participation in scientific discourse.
As pointed out already, the intent of this study was not to criticize a science teacher. Rather, our concerns were in understanding how a specific teaching practice was mediated by particulars of the setting. Our ultimate goal was to arrive at one or a series of recommendations that could be a starting point for an action research project. We believe that a social practice view of knowledge provides teachers with a new referent that would entail changes in actions and classroom climate more conducive to learning from demonstrations.

**Recommendations from A Social Practice Perspective**

From a classical perspective of knowing and learning, Mr. Sparks has done many things appropriately. A classical perspective of knowledge treats it in modular form. Words (concepts) have meaning and refer to ontologically real objects. Looking at real objects and events provides a direct view of the concepts. Through observations, individual students are enabled to see the underlying structure. The teacher has only to provide the correct labels (we note that this is also a central part of other teaching strategies such as the learning cycle). For example, in a classical perspective, a reasonably intelligent student would be able to put together the idea of the thumbs-up into an arrow, given the knowledge that vectors have magnitude and direction. From a discourse perspective, any one of the three ways could be appropriate as part of the discourse about angular momentum of the bicycle wheel, and replace the other two. The important difference is that the alternate signs can be learned only in practice, for their meaning is always given by the place they take in the current social practice. We therefore suggest a perspective in which all activities, doing experiments, talking about design, explaining phenomena, constructing representations, and so forth are considered social practices. These are shared, developed, and negotiated within specific communities of knowing (Roth & Bowen, 1995).

A social practice perspective would help Mr. Sparks to view learning as one of participating in practices of seeing, manipulating the world, separating signals from noise, talking about phenomena, constituting phenomena through adjustment of discourse, representing phenomena in terms of vectors, and constructing invariants (not finding or discovering invariants). A social practice perspective would help Mr. Sparks to recognize that to share meaning, people have to engage in and develop practices together, be able to negotiate understandings, and repair discursive trouble (misunderstandings and errors). It would help him to recognize that in his classroom, and especially around the demonstrations, there was a lack of opportunities:

- for discussion that would have helped Mr. Sparks to understand what students did not understand;
- for the students to check whether their own talk about the phenomena was shared with others or was viable and fruitful, or whether it needed to be changed;
- to check whether what students constructed as a phenomenon was, from a scientific perspective, the phenomenon to be of interest or simply noise.

Our assessment is consistent with the finding that a key aspect of learning to design is students’ opportunity to engage in architectural discourse with a studio master (Schön, 1987). In Schön’s study, students and studio master engaged each other in making sense of their respective talk. The students’ first sketches and the studio master’s additions constituted the focal artifacts that allowed a common discourse to emerge. They held the conversation together. In the course of their studio course, students developed new competencies in talking architectural design, and the studio master learned new ways of talking with students who were more peripheral members in the architectural discourse community.
Some of the things a social practice view of learning would suggest to Mr. Sparks about modifying his demonstration-related teaching include:

- Engage students in talking about and representing phenomena;
- Engage students in discussion about scientific inquiry and the construction of variables such as to produce a consistent theoretical framework and construction of variables that allow them to keep account of systems despite change;
- Engage students in discussion about the mutually constitutive function of the language game and phenomenon, situated language, and knowledge which assists in the separation of signal from noise;
- Have students generate evidence and theory, set up a forum in which these are hammered, and decide on future evidence to be needed and constructed.

For teachers who adopt a social practice perspective, learning environments will change. These are then no longer considered places where experts transfer their knowledge and products to less expert others. Rather, learning environments become places where all participants engage in developing new and common social practices (doing practical things, describing events, talking theory, etc.). These new social practices have to develop out of previously existing ones if they are to be robust and connected instead of piecemeal. There is evidence that such an approach works. Rather than imposing their computer-based work places on users, Scandinavian design engineers began their work with mockups to establish a common discourse between professional designers and future users (Ehn & Kyng, 1991). In the process of talking about relevant artifacts, this common discourse began to change as the artifacts evolved; and with the evolving artifact, designers’ and users’ mutual understandings changed so that in the end, an intelligible and functional workplace emerged. In the same way, the already mentioned architectural students produced initial designs which became artifacts over and about which they engaged in conversations with the studio master. Students learned architectural design discourse by beginning where they were at the moment, and by changing this initial discourse in the course of talking to a member of the design community.

One of the things teachers such as Mr. Sparks may want to try is to present a demonstration followed by student discussion, and presentation of a canonical framework with vector representations both in parallel and in orthogonal orientations. This may help students develop explanations in which the conservation of angular momentum, the relationship between the relative angular velocities (moments of inertia), and the influence of friction on the system are important resources—there is evidence that such an approach works. We showed that Grade 6 and 7 students could engage in a lengthy argument about the outcome of a tug-of-war between themselves and the teacher who was assisted by a block and tackle (Roth, 1996). In this case, students and teacher moved from talking about the event and the actual block and tackle to the chalkboard where their discussion evolved around representations, both simpler and more convincing than the actual artifacts. (This is also in line with Latour’s [1987, 1993] observations that plane representations are much more powerful and convincing in scientific rhetoric efforts.)

From a social practice perspective, Mr. Sparks would not need to be as concerned with situated errors that he repeatedly pointed out in his own presentation while reviewing classroom episodes. For example, he suggested that because of the conservation of angular momentum, moment of inertia ($I$) and angular velocity ($\omega$) were related so that $I\omega^2$ (“I’d have to do an $I$-omega squared’’ for the wheel”) rather than the correct $I|\omega|$ remained constant. From a traditional perspective of information transmission, this is serious, because he had transmitted wrong information which he had not corrected. From a social practice perspective this is not as serious,
because slips such as this are repaired as part of ongoing activity as soon as any one participant in the interaction would question the statement. Conversational repair is one of the features of shared discourse that make language so efficient (Clark & Schaefer, 1989; Stuckey, 1990).

What teachers can gain in adopting a social practice perspective of teaching and learning physics is especially captured in the following episode from our study. After the posttest on rotational motion, one of us commented to a group of students, “Thumbs-up.” The students looked at him in a perplexed way, evidently not understanding what his comment could or should mean. In the context of our particular test, and within a community of physics teachers, the relationship between “thumbs-up” and the right-hand rule (thumb sticking up from curled hand) that would provide the answers to many of the posttest questions is an opportunity for a humorous comment. However, what the speaker had not realized is that to understand this humor, one has to be part of the discourse community. This in-joke is comprehensible only to those who are already competent participants in the community (fluent speakers).

Can teachers such as Mr. Sparks change? What it takes to change so that teachers draw maximum benefit (in terms of student knowing and understanding) from their demonstration depends on each individual. Thus, it is difficult to generalize and make recommendations that are transferable to other situations. However, we can ascertain that Mr. Sparks, in a few instances, already used a discourse that could become pivotal for a change process (given that he desires change) in which he could engage with a facilitator. In our interviews and debriefing sessions with Mr. Sparks, it became obvious that he already shared with us some common language on the basis of which further modifications of his demonstration practice could be intelligible and plausible. For example, he described the differences between his own and students’ discourse that were related to the differences in describing, seeing, and explaining demonstrations in canonical ways.

Because my mind is going ahead of theirs. I’m working from a platform at this level, whereas this is their first exposure to it and I see what I’m expecting to see and they’re not seeing what they’re expecting to see, or they don’t see what I think is evident. (Mr. Sparks, 0824V1)

Mr. Sparks also knows that students may need to spend time in discussion. He suggested that explaining one’s ideas to others is an important aspect in coming to understand, both in his own and students’ learning:

People don’t understand it unless they can go through that process—and why do I say that? Because as a teacher, I might have taught complex numbers for some years, but it’s only when I’m invited to run a seminar or workshop for other teachers on complex numbers that there are some aspects of it that never occurred to me before that, and I see that in myself just over the years and so it’s the same with them. (Mr. Sparks, 0824V1)

We suggested the use of a facilitator, because at that moment his discourse interacted with others. A facilitator may be able to help him negotiate his own contradictions. For example, although he suggested discussions as a learning strategy at home, and to seek opportunities for asking for or giving help, he did not provide for such opportunities in the classroom. He also argued that by permitting time for student talk, the continuity of the demonstrations was interrupted, a continuity and variety which keeps his own interest and motivation (“[I am] excited at just going on to the next one, and before you realize it, you’ve covered a wealth of information”).

We provided here some suggestions that could be taken as a starting point for an action re-
search project if a teacher appropriates the concerns we raised. The bonded nature of the study (6 weeks) and the availability of the full analysis long after two of the authors had left the site precluded such a project. We had, however, some conversations with Mr. Sparks about the possibility of addressing some of the concerns raised in this study. He suggested that whereas he recognized the utility and need for a more social-constructivist, he could not teach in the way the first author had done during his own teaching (e.g., Roth, 1995, 1996). We explore these and related constraints experienced by Mr. Sparks in great depth elsewhere (Roth et al., 1997).

Implications

This was but one teacher’s practice of demonstrating, and we are careful not to make the claim that our descriptions, explanations, and recommendations are transportable to all other situations. Based on our own experience as supervisors of teachers in science departments and as teacher educators, we believe that the results of our study may prove fruitful for making sense of other science classrooms as well. It appears to us that if teachers could view knowing science as competent participation in science-related discourse—depending on the nature of the course, this would be the discourse of public policy debate (e.g., about science–technology–society issues), scientific research (for graduate students), applied science (e.g., technicians), and so forth—they would be able to resituate their demonstration practices and make the involved objects and events focal points of discussions. Increasing discursive competence during these discussions would signal to teachers that students were learning.

Interesting new research questions would arise in classroom environments redesigned according to our recommendation: How do new discourses evolve from the interaction of students and teachers about demonstrations? How do students come to see teacher demonstrations in canonical ways? and How do historical and meta-theoretical discussions about the demonstrated phenomena interact with students’ learning?

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Note

1 All names are pseudonyms.

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