Dialectical Constraints to the Discursive Practices of a High School Physics Community

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Received 25 July 1995; first revision 26 February 1996; second revision 10 October 1996; accepted 6 December 1996

Abstract: The study investigates how the discursive practices in a physics class were constrained by social forces associated with the larger context in which teaching and learning were situated. The teacher understood teaching and learning in terms of constructivism, believed that students should have more autonomy in the classroom, and structured activities to involve students actively in the learning process. However, despite his efforts to enact the curriculum in a manner that was consistent with constructivism, the emphasis still was on goals such as learning to use formulas to perform calculations and memorizing facts. In addition to constructivism, belief sets that shaped the enacted curriculum related to time being scarce, content coverage being a primary concern, and students needing to be prepared for examinations. A characteristic of the classroom community was a relative imbalance between the voices of science and common sense. Even though the teacher was concerned with students making sense of physics, examples are provided of students accepting the viability of scientific claims despite contradictions with their common sense notions. J Res Sci Teach **34:** 491–507, 1997.

Introduction

This study investigates the belief sets embedded within the discursive practices of the teacher and students in a physics class. Beliefs are sometimes naturalized and regarded as common sense, and at other times they are foci for struggle and change as teachers, students, and other stakeholders endeavor to negotiate a shared language and foster coparticipation and thereby to move a classroom community toward a particular vision (Tobin & McRobbie, 1996a). We assume that being able to make sense of the language of a classroom and learn is an essential component of empowerment. Gilbert and Low (1994) emphasized that power relations, as they are represented in diverse discursive forms and practices, often are regarded as normal, and as

Correspondence to: K. Tobin
Contract grant sponsor: Australian Research Council

Published by John Wiley & Sons, Inc. CCC 0022-4308/97/050491-17

such are social forces that constrain the actions of members of a community. Tobin and McRobbie (1996a, 1996b) reported how the discursive practices in the classroom of a 20-year veteran chemistry teacher were constrained by social forces described as cultural myths. Although the teacher believed he should act in particular ways, his actions and those of students were constrained by four cultural myths related to the transmission of knowledge, being efficient, maintaining the rigor of the curriculum, and preparing students to be successful on examinations. These social forces were associated with the situation of his class in a larger context of an educational system.

The following vignette from a Grade 11 physics lesson on relativity provides a context for exploring the relationships between power and knowledge. Since the teacher in this study, Mr. Morrell (a pseudonym), taught in the same school that participated in the study undertaken by Tobin and McRobbie, we regard it as highly likely that social forces similar to those listed above would constrain the practices of the teacher and learners in this physics class. We began the study with an interest in identifying the referents underpinning the enacted curriculum and understanding the relative power distributed between Morrell, his students, and the institution of science as the participants endeavored to attain their goals in a physics classroom. At the time of the study Morrell was in his second year of teaching.

Questions about Power and Knowledge

The lesson began with a discussion of relativistic effects of mass and time. Mr. Morrell reviewed the use of a formula and then allowed students to work on some examples that enabled them to see that the mass of an object changes appreciably when its velocity approaches the magnitude of the velocity of light. Counterintuitive aspects of physics, such as the velocity of light in a vacuum being constant irrespective of the observer's frame of reference, were presented by the teacher as facts, claims without evidence. Morrell demonstrated how to use the formula and then students used it to complete several exercises. That is, they practiced applying the formula in a technical manner, and little attention was focused on understanding the conceptual aspects of the associated physics. Students were clearly excited by what they were hearing because it was counterintuitive, but there were no challenges to the scientific claims. The tendency was to accept the claims as viable and express amazement at the consequences of so doing.

Morrell used space travel to illustrate frames of reference and time dilation. He explained that traveling at the speed of light, it would take a person 4.3 years to reach Alpha Centauri, and used a formula for dilation of time to show that to the person traveling in the space vehicle, the time would be shorter. A brief discussion ensued during which Brian (a student) raised the social issue of a traveler, on return, being younger than those who remained behind. Without discussion of the feasibility of traveling at relativistic velocities or on the size of the universe, Morrell remarked that a person could traverse the universe in a human lifetime.

Morrell wrote the formula for time dilation: $T_v = T_o(1 - {}^{v2}/_{c^2})^{-1/2}$ on to the board and paused for students to copy it into their notes. "These formulas have actually been proven in cyclotrons," he explained. When the lecture was completed, students applied the formula in an exercise in which a space craft was moving at 85% the speed of light.

The vignette describes a lesson that focused on the use of formulas and omitted discussion of the physics associated with the terms, numbers, and calculations. Earlier studies in which we have been involved had a similar pattern suggesting that students' understandings of science frequently were limited to rote learning, recall of facts, and application of formulas (e.g., McRobbie & Tobin, 1995; Tobin, Kahle, & Fraser, 1990; Tobin & Gallagher, 1987). The question of how the content of physics relates to daily life experiences is raised in the vignette. Students did not discuss the feasibility of ever traveling at the velocities they plugged into their formulas, but romanticized the consequences of so doing, accepting the formulas as given, truths that were beyond their questioning voices. Although there was discussion, we observed no evidence of students attempting to identify and clarify differences in their understandings of the world in which they live their lives and the fantasy of unimpeded relativistic travel throughout the universe.

To what extent is knowledge of physics coherent with everyday knowledge? Many studies suggest that everyday notions about phenomena are viewed by learners as compelling and are retained alongside knowledge of canonical science, although the sets of constructs are often irreconcilable (e.g., diSessa, 1986; Driver, Guesne, & Tiberghien, 1985; Hawkins & Pea, 1987). What forces compel teachers and students to act in classrooms such that the patterns described in the above vignette are commonplace?

Theoretical Perspectives

What we have learned from this study is grounded in our histories and builds on our knowledge as science teachers, science teacher educators, and researchers. We regard the physics classroom as an evolving community of practice in which the discursive practices (e.g., talk, writing, cognition, argumentation, and representation) of participants are constantly changing in response to the actions and interactions of a teacher and students, not only with one another, but also with social structures such as conventions and norms (e.g., McGinn, Roth, Boutonné, & Woszczyna, 1995; Roth, 1995). Discursive practices involve text production, reproduction, and consumption, where text is broadly defined as any written or spoken product (Fairclough, 1992). Learning occurs within a constantly evolving community that involves dialectical struggles in which "members' practices are shaped in ways of which they usually are unaware by social structures, relations of power, and the nature of the social practice they are engaged in whose stakes go always beyond producing meanings" (Fairclough, 1992, p. 72).

If students are to learn science as a form of discourse, then it is necessary for them to adapt their language resources as they practice science in settings in which those who know science assist them to learn by engaging activities in which coparticipation occurs (Schön, 1985). That is, all students have access to and can appropriate a shared language to communicate with one another in such a way that meaningful learning occurs. The shared language must be negotiated and would enable all participants in a community to engage the activities of the community. Students receive opportunities to practice and observe others practice such that at any time, a person might be both a teacher and a learner with respect to others in the community. Coparticipation implies that a concern for facilitating one another's learning and peer teaching is a critical constituent of such an environment. During interactions among participants, respect would be shown for the knowledge of others and efforts would be made to find out why particular claims were regarded as viable. There would be concern for knowing in a way that is scientific and the knowledge that is learned within the community would be consistent with canonical science. Within this evolving community, concern would be shown for what is known by learners at any given time and how they can represent what they know.

Power, which is conceptualized in terms of being able to appropriate a shared language, would be equitably distributed among the teacher and students such that knowledge claims that made no sense would be clarified and discussion would occur until such time that a learner was satisfied that she or he then understood. In a setting in which coparticipation was occurring, students would have the autonomy to ask when they did not understand and the focus always would be on what students knew and how they could represent what they knew. Students would not feel that they could not understand and that their only recourse was to accept what was being said as an article of truth based on faith that other authoritative sources understood the warrants for the viability of a claim. Thus, coparticipation would involve discussions in which participants tested one another's understandings and were sensitive to their roles as both teachers and learners.

Methodology

The study employed interpretive procedures (Erickson, 1986) that followed a hermeneutic cycle (Guba & Lincoln, 1989) in which what was learned was informed by what was already known from our own research (McRobbie & Tobin, 1995; Tobin & LaMaster, 1995; Tobin, Tippins, & Hook, 1994), reading of the literature (e.g., Fairclough, 1992; Gilbert, 1992; Gilbert & Low, 1994; van Dijk, 1993), experience in the field, and continuous data framing, analyses, and interpretations.

The research incorporated two broad views of social phenomena, actor-oriented and structure-oriented, understood to exist in a recursive relationship to one another (Galtung, 1980). Whereas both perspectives focus on human action and interaction, the actor-oriented perspective perceives action as related to the intentions and capabilities of individuals while the structure-oriented view regards action as a function of the position of individuals in social settings. Thus, the actor-oriented perspective focuses on actions in terms of actors' goals, beliefs, behaviors, and constructions of context, and the structural perspective examines factors associated with power differentials. Neither view is regarded as privileged, and each contributes to the description of what is happening and why it is happening, the two fundamental foci of interpretive inquiry.

In July 1993, the three authors of this article commenced daily observations of teaching and learning in a Grade 11 physics class. The observations continued for 4 weeks. Then, Anderson, the teacher in this study, had a continuing presence in the school; McRobbie visited the school periodically as part of an ongoing investigation of professional development undertaken in collaboration with the school; and Tobin returned to the school in 1995 to participate in additional activities associated with data framing, member checks, and peer debriefing for this and related studies.

Researchers' Roles

Our decision to use a pseudonym for the teacher acknowledges that our research focuses on a 2-year period and reports only part of the myriad stories that together describe Anderson the teacher–researcher–coauthor in this study. Anderson taught physics for 3 years before commencing a doctoral degree in science education. As the teacher in this study, he was able to provide an insider's view of the struggles involved in implementing a physics curriculum in ways that conform with the visions of reform and his own beliefs about teaching and learning. Whereas Morrell (a pseudonym for Anderson) lives only within this article, Anderson learned from his involvement in the study and continues to learn and change as his career as a science educator unfolds. Because this article cannot describe these changes, we felt it appropriate to describe the teacher in this study by a pseudonym while at the same time acknowledging the courage underlying Anderson's decision to identify himself as the teacher in the study. By so doing, readers of the study are afforded a unique opportunity to examine the extent to which detailed analyses of teaching can provide bases for critical reflection and the catalysis of change. In the adoption of our position with respect to Anderson and whether to use a pseudonym, we were cognizant of other studies in which this was an issue (e.g., Tobin & LaMaster, 1995), and we empathized with the following comment from Gulyas, also a teacher in a study (Gulyas, 1994, p. 189):

> In other people's minds, I may only ever be the person described in the research, static and finite, lacking dimension or the certainty of growth and change. The article . . . offers only a glimpse of an ongoing story, one chapter of a longer, more complex book. The beginning of the book is unknown, and the ending hasn't been written yet.

We adopted multiple theoretical frames to make sense of our roles and relationships with the participants in the study. Our orientation was to understand how Morrell and his students described what they did in the classroom and how they justified what they did in relation to the enacted curriculum.

We negotiated entry into the school site to undertake research that would provide a platform for changes to be considered later by school faculty. We listened with empathy to the stories of teachers and students and did not counsel or suggest alternatives. When appropriate, we assisted students with their learning. Throughout the study, we did not endeavor to initiate reforms, although by providing teachers and students with field notes, interviewing them, and providing them with transcripts of the interviews, we acknowledge that a context was created in which the reflections of all participants were different from what would have been the case had we not been there. This was a participant observation study where the presence of the researchers changed what happened. Although we did not expect teaching and learning to change to conform to an a priori vision of appropriate practice, we did expect changes to occur as a result of participating in the study. As changes occurred, we endeavored to describe and interpret them in a context that took account of our presence.

The Setting and Participants

The site of the study was a comprehensive inner-city high school with a diverse student population of approximately 2,000. A wide diversity of courses, the availability of independent study programs, and the central location of the school make it a popular choice for students. McKibbin, Cooper, Arcodia, and Doig (1995) reported that among the reasons provided by parents for their children attending the school were expectations for high academic achievement, obtaining a well-rounded education, good subject selection, and a supportive learning environment. More than 80% of parents regarded the teaching at the school as effective.

Although the school is diverse with respect to country of origin of the parents, almost 80% were born in a country described as Anglo (e.g., Australia, New Zealand, England). Approximately 20% of the families completing a questionnaire reported that they spoke a language other than English in the home; however, those with limited English proficiency were most likely not to respond to the questionnaire, an assertion supported from the school records that indicate 36 languages other than English were spoken by students at the school. In other publications from this research, we have reported our investigations of limited English proficiency and the learning of chemistry. In this physics classroom, consisting of 8 males and 4 females, there were 4 Asian students with limited English proficiency. The problems they experienced are similar in nature to those described by Tobin and McRobbie (1996b) for students (some of whom were the same) in a Grade 11 chemistry class at the school.

Science in Grade 11 is elective for students, and it is customary for only the highest achieving students to be advised to enroll for physics and the required corequisite mathematics courses. Accordingly, those studying physics tended to be high-achieving students, many of whom selected physics because it is required for acceptance into their preferred university degree. It is not uncommon for universities to require studies in physics as a requisite for entry into prestigious professional degrees such as medicine and engineering.

The researchers visited the physics classroom each day of the week for 4 weeks, to observe a unit that explored force, motion, and relativity. Each lesson was videotaped to facilitate analyses of classroom transactions. Since we were in the field for a prolonged time, the tendency of participants to exhibit contrived behaviors for the benefit of researchers was minimized, and we were able to see whether given behaviors were typical or atypical. We maximized the probability that the emergent assertions were consistent with a variety of data through the use of the following sources: field notes and analytic memoranda based on observations of teaching, interviews with the teacher, and videotaped lesson segments.

Morrell was interviewed on numerous occasions each of about 30–60 min duration. All interviews were transcribed and edited to ensure that they read like written rather than oral texts. In this process, repetitive phrases and false starts were removed and verbal fillers such as “urr” and “ah” were deleted. Because of these transformations, we returned the written text to Morrell and asked him to identify sections that could be changed to improve the authenticity of the narratives. Morrell suggested minor changes and all were undertaken.

Rather than present what we learned about the beliefs of the teacher and students as a set of assertions, these outcomes were constructed as a narrative for Morrell and three vignettes that highlighted what we considered to be reflective of salient dimensions of the enacted curriculum. The narrative was prepared from transcripts of interviews with Morrell. The researchers examined the interviews in relation to the text of this article to identify segments that were relevant to the assertions of the study. These segments of text were then ordered so as to form a narrative that was coherent with respect to issues that Morrell had discussed in the interviews. To the greatest extent possible, we used only words that had been uttered by Morrell, but we arranged the speech segments as a rhetorical event concerning teaching and learning to provide insights into an evolving community of practice. Morrell edited the narrative and agreed that the text was authentic as a separate entity and in its manifest intertextual form within the article (Fairclough, 1992). Excerpts from the narrative are used in the article as thick description, evidence to provide support and contextual grounding for assertions.

The three vignettes were prepared from field notes based on our direct observations, repeated viewing of videotapes, and analyses of transcripts of the lessons. The vignettes are narrative accounts of stories that are salient in the sense that they are representative of events that occurred throughout our observations and were regarded by the researchers as having theoretical and applied significance. Morrell read the vignettes on several occasions and was asked to make any corrections he wanted so as to make them more authentic. Morrell engaged in intensive discussions on the vignette used to introduce this article and, in addition, wrote reflective commentaries on the two vignettes that follow this section of the article. These commentaries were edited by deleting segments regarded by the authors of the article to be not pertinent to the study. Morrell read the vignettes as separate texts and in their intertextual place within the article and agreed that they were authentic accounts of what happened.

Throughout the study, the three researchers met regularly to discuss and analyze data and formulate assertions that provided foci for subsequent field activities in the sense that efforts were made to obtain data that supported and refuted them. Any evidence that was counter to an assertion was explored in detail, and care was taken to build an understanding of the discrepancy. In this process, assertions were elaborated to take account of all data. All written texts were shared with participants so that they could check our interpretations, identify errors that might have been made by either the participants or the researchers, elaborate, summarize, agree or disagree, and offer suggestions to improve the authenticity of the research. For example, Morrell was provided with copies of all field notes, in which we often wrote questions to which he responded, and transcripts of interviews. He also responded in writing and orally to all versions of this and other articles in which he was a participant.

The process used in writing this article was for the first author to write an initial draft using the three vignettes and highlighting assertions that were consistent with the interpretation of all of the physics data. Thus, the assertions were foci around which we built arguments to illustrate the principal findings of the study. The coauthors read the initial draft of the article and suggested changes, all of which were implemented. Multiple rewrites of the article were undertaken until each author agreed with all parts of it.

The following sections of the article present the vignettes, narratives, and associated interpretations that highlight patterns and changes to the discursive practices of the teachers and students, the members of an evolving community of practice.

Evidence of Struggle between New and Old Practices

Morrell was aware of some limitations in the way physics was taught traditionally, and because of the value he placed on student autonomy, he wanted to implement the curriculum in such a way that students had greater autonomy. Thus, the actions and interactions in the classroom were shaped by Morrell's beliefs on autonomy, which are represented below as excerpts from his narrative.

> I don't think there is a great deal of autonomy for students in this current system. I guess in an ideal world I'd have them inventing their own experiments for the given curriculum that we're studying and being able to implement that in their own time. But that's not a possibility given timetabling restrictions and those sorts of things. There is a degree of autonomy in their program. There is a body of problems, and problem sheets that they have, and I say, "Well you have to do these," and I don't go around saying "Complete this tonight, that the next night." I generally leave that to their own discretion as to how they organize their study programs. There's autonomy in that respect, but I have a feeling there's a lack of autonomy in the classroom at the present stage.
>
> Students also have control in so far as selecting who they want to work with in labs. I don't say *XYZ* work together. I say, "Get yourselves in groups of three, no more than four, equipment is over there—go ahead," and off they go and I wander around. If they have any problems they will usually call out or they will ask someone else in the group and get cooperation from other groups. I see that happen lots and I could almost walk out of the classroom totally. In some cases they do it all themselves so they have a lot of liberty as far as that is concerned in the practical sense.
>
> I would hope that they are at liberty to bring forth their ideas and knowledge, but I think there are some forces at work that are possibly preventing kids from disclosing their notions and ideas. This concerns me a bit.

Underlying Morrell's beliefs about student autonomy is a set of beliefs about the nature of learning and knowledge, which he referred to as constructivism. Morrell's use of constructivism to think about teaching and learning and to create a vision of what his classroom could be like sets the stage for a struggle because, as was evident from the opening vignette, there are practices that occur routinely that are in direct opposition to those that would be consistent with constructivist semantics. Morrell's most significant beliefs about constructivism are presented below.

> My principal goal is to teach in a constructivist format. I don't concur with the theory that students are empty vessels and that I, as the teacher, pour information into them. Students are learners, they are programmed to be learners from the beginning of life. We as individuals learn things every day without being prompted by anyone. It is the nature of our makeup that we take in information, we construct it into our consciousness to varying degrees depending on how important we perceive it to be. So I can't, as a teacher or

> as an individual or a human being, make another person learn. All I can do is make an environment that is fostering or nurturing to the individual to learn and that's what I attempt to do in my classroom.
>
> Constructivism assumes that individuals construct their own ideas. They come to a classroom environment with a set framework of ideas and notions and concepts and new information is incorporated into that framework and as to whether it's subsumed correctly when information isn't properly connected in the framework then there is a potential misconception that can occur. Students connect new learning to what they've learnt in the past. The physics that we're dealing with is pretty well always built on previous concepts. So, it's not like, "Right-o, we're finishing the kinematics, put that away. We're never going to need that again." It is always coming up.

During the observational period there were numerous activities in which Morrell enacted the curriculum in a manner that would best be described as student centered. On such occasions, interactions between students were most prominent and those involving the teacher and students usually were restricted to Morrell speaking to individuals. Presumably these activities were those planned to accord with constructivist semantics. A description of one such activity was a part of Morrell's narrative and is included below as a precursor to the next vignette.

> One of the interventions that I employed in my physics classes, in order to promote greater levels of constructivism and relinquishment of my power, was to assign students the task of designing complex order problems of the kind which they were used to encountering in the physics examination. I knew the great value of this process from first hand experience, in that the process of designing complex application type questions for examinations was a high-order cognitive process and causes one to deliberate intently upon the many domains of the topic at hand. I reasoned that this thinking process was highly beneficial towards the construction of the students' own knowledge about the topic of force and motion, and further, how this knowledge relates to other bodies of knowledge. In the process of developing these questions, students are in a sense forced to consider how one domain about physics relates to other domains. One of the very strong advantages, in my view, of this process is that as students focus upon these relationships, alternative frameworks may become evident and may cause cognitive dissonance which will hopefully cause the students to reassess their knowledge in light of the constructs which do not fit well into their existing cognitive framework.
>
> Students initially had some difficulty in the process of designing a complex application question. For almost all of them this was the first time a teacher had asked them to actually design a question as opposed to answer a question. I moved from group to group and offered very general, nonspecific assistance in terms of encouraging students to blend a variety of concepts in their questions and avoid one dimensional type problems. The process of sharing the developed problems took the form of one or two members of each group adopting control of the classroom environment and presenting a written form of the problem to the rest of the class. Questions of clarification were permitted to be asked of the presenters and then a period of time, usually about 10 min, was allocated for the class to attempt to solve the problem. During this time I either attempted to solve the problem myself or observed other students around the class solving the problem. Following this period, the presenting students elicited a solution from the other students. I encouraged the presenters to adopt my role and attempt to probe and question students for answers rather than just present the solution.

Although Morrell was overt in his claims to use constructivism as a referent for his teaching and he was supported by his graduate studies to continue to try to enact the curriculum in ways that were consistent with constructivism, there were signs of struggle in the discursive practices of the community. The following excerpt from Morrell's narrative provides insights into his awareness of this struggle and the lure of teacher-centered activities.

> It is a discipline to make yourself teach in a constructivist mode. It's very easy to fall into that teacher-centered model. Its easier to teach that way; you can get up there and start to transmit information. If I were to do my own self-assessment and say well how am I going, I would say that I am making progress in teaching in a constructivist mode.

The Prisoner and the Guillotine

Morrell's evaluation of his own teaching indicated that he felt that he had not accomplished his goal of maintaining an environment that was conducive to learning. We concur with his evaluation. Technical interests seemed to characterize the curriculum, and conversations with and between students were about getting right answers and efficiently completing assigned tasks. Absent were conversations or arguments about the interrelationships among the concepts of physics. However, Morrell was concerned about giving the students more autonomy to pursue problems that had potential relevance to them and, as described above, he asked the students to formulate a task to synthesize knowledge of forces and motion. Having developed a task, each group was to obtain a solution and then present the task along with those from other groups as a set to be solved by the class as a whole. When the tasks were completed by the students, one person from each group conducted a whole-class activity during which the original solutions to the tasks were presented by a selected group member. The following task was developed by a group of male students and its solution was presented by Brian, a student who had lived much of his life in Switzerland: A man sentenced to the guillotine has decided to pass the time working out the physics behind the process. It takes a minimum velocity of 9.5 ms^{-1} to cut off one's head. The mass of the blade is 5 kg. What is the required height of the guillotine? What is the force required to cut off a person's head?

Calculation of the height from which the blade needed to be dropped to reach the minimum speed was a routine matter for most students. Not quite as straightforward was the calculation of the force with which the blade impacted the neck of the criminal. Brian, a student from the group that had formulated the problem, calculated a solution for the class. The force of impact of the blade on the neck was reasoned to be equivalent to the gravitational force on the blade. The answer was readily accepted by Morrell as correct ("Which is, of course, the same as we get if we use $F = ma$. That's great! Thanks Brian!").

To one researcher in the class at the time, the solution seemed counterintuitive. The following comments taken from a transcript of the lesson show the essence of his concern.

> . . . Intuitively it seems wrong, because the force would be greater if you drop it from 10 m than if you drop it from 2 cm, or than if you don't drop it at all. So if I'm the person who is to be beheaded and I get a choice, I'll say, "Don't raise that so high, just give me the 2-cm drop."

The researcher was the only person in the class to raise a question about the viability of the solution. The teacher defended Brian's answer (". . . It's the same amount of force if you drop it from 1 m as 100 m, according to $F = ma$"). Eventually the teacher made the following concession:

> Yeah. There's something not quite right. There is something not quite right about that. I

> have thought the problem out once before. Not this problem but a similar one, and I can't for the life of me remember the reasoning for it, but I will.

There was no effort on the part of the teacher, Brian, or the other students to consider what physics they knew that might lead to an alternative solution. Throughout the short interchange, Brian remained at the front of the room and endeavored to counter the suggestions of the researcher and defend the viability of his group's solution ("In this problem . . . we assume that the body has no resistance; there isn't any friction"). However, when the lesson concluded, there were no further attempts to resolve the contradiction that was present for just a short time. The matter of the force required to sever the head of the man was no longer an issue. The next lesson dealt with new content and there were no subsequent conversations about the task or its solution.

Morrell's response to this vignette was to identify three factors that constrained his preferred actions. These relate to his being forced to cover too much content in the time available, a perceived shortage of time, and the imminence of an examination. His response follows.

> This task was given to the students at the end of a unit of physics as part of some revision and consolidation activities. Given that there were six groups in all, the process of designing problems and sharing these problems with the rest of the class was time-consuming. The number of available lessons in a school term was few in light of the amount of curriculum I was forced to cover. In addition, the pressure of meeting the examination schedule was an ever-present concern to me. I estimated that the question designing process would take about a lesson and a half, and the sharing process about three lessons. In effect, this was a week's worth of activity, a fact that caused me some underlying tension given the aforementioned pressures on time that I was constrained by in the environment in which I worked.
>
> Brian's group was one of the last to present their question. I did not actually solve this problem myself, but was probably involved in observation of other students. The solutions of students at this stage of the activity were not heavily scrutinized, but were all too easily accepted by myself and, as a result, were accepted on faith by all other students in the class. The cues I enacted in accepting Brian's solution, ending discussion, and moving on to another segment of the lesson were completely sufficient for the students to fully accept this solution on the basis that I had accepted it. With hindsight, the amount of power that I held as a teacher in that context was indeed astonishing.

Morrell's views on the presence of social forces that shaped the curriculum are further exemplified in the following excerpts from his narrative. He believed there was a shortage of time to cover the content included in the curriculum. This belief made it difficult for him to justify taking additional time when it appeared that some students did not understand. This tendency has been noted in other studies (e.g., Tobin & Gallagher, 1987). The effect was to focus more on features of the content and less on the extent to which students were learning with understanding. Furthermore, taking the time for conversations or arguments over explanations in relation to data was difficult to justify because of the belief that certain content had to be covered and there was a shortage of time to cover all of the content.

> The biggest overriding factor that I've seen is the time limitation; we've got *x* amount of time to do *y* amount of stuff. These sorts of activities, where you're getting them to design their own experiments, are time-consuming. . . . I mean, we are working within a time limit. There is a lot of work to be developed in that sort of curriculum. Even the textbooks are currently designed around the format of our syllabus. It is pretty jam-packed—you

> can't afford to rest on your laurels. There is a lot of information to get through and the course is based on information. There is a lot of information and you can't afford to vary too much from the approved program. There is some point that you have to cut and say, "We have to go on."

Despite the perceived shortage of time, Morrell firmly believed that he should set activities to promote learning with understanding. An excerpt from Morrell's narrative states that:

> Core concepts are developed in class along with the more refined detail and implications. I am getting the kids to actively sit there and think about core concepts and the implications they have. How do they fit in? That activity I am making them do fits well into the learning process. There is great value in the process of sitting down and having a think about physics, not doing a problem, not solving a mathematical problem or solution, but just to sit there and think about where particular ideas really fit in. If there are other areas of their domains of their cognitive framework to link in with, and it is meaningful to do so, you won't have isolated concepts.
>
> One exercise I'm currently getting them to do is with reflective thinking. I've set them a task whereby every night they record a journal of today's lesson and they have to answer four questions. What were the main points of the lesson? How does this information we've talked about in the lesson relate to other bodies of knowledge? How can it be applied? The other two questions relate to what they found most difficult and what they found most interesting.

Morrell was certain about a requirement that he teach specified content. He believed others were responsible for selecting content and making sure that the course was not watered down by covering less. The following excerpts from his narrative provide evidence of his conviction that others were in control of the specification of what was to be taught.

> I am not the physics coordinator. The course coordinator and the administration require that this amount of the work program has to be covered in an allocated time. We are committed to the work program because it has been accepted by the board, and therefore we have to meet certain criteria expressed in the work program. I think the work program has been around for a while. I don't know who wrote it. I think it is almost universally accepted across the state actually that we do it in that order. But it has to be accepted by the board. They are very stodgy. There is the accepted way and no other.

Even though Morrell was able to transfer control to students for decisions about what to do, how to do it, and when to undertake tasks, the microculture of the physics classroom constrained the actions of students in significant ways. The students' own ways of making sense were set aside in favor of the semantics of physics. It was not customary in this class to ask for evidence to support the viability of a particular solution, nor was it common to challenge solutions to assigned tasks. Accordingly, when one of the research team challenged the solution to this problem on the grounds of common sense, the challenge was not taken seriously and was not pursued as an opportunity to learn physics. If the researcher's warrant had been based on one of the theorems of physics, it would no doubt have been dealt with differently. For example, if the researcher had asserted that Brian's solution did not take account of the total energy of the blade, only the potential energy, then the claim would more likely have been taken seriously, because one claim based on physics knowledge was being challenged in terms of another claim from the physics domain. This issue is significant, because most students feel intimidated in bringing forward challenges when the basis for their challenge is their everyday commonsense knowledge.

In establishing a community of practice in the classroom, Morrell had not promoted the custom of justifying solutions, actively seeking alternatives, and selecting from the alternatives the most parsimonious of the viable solutions. Furthermore, and of importance from a constructivist perspective, students were not encouraged to speak up when claims made no sense to them. Perhaps they did not see their own knowledge as a foundation for making sense of physics and developing the discursive practices of a community populated by those who know physics.

At a structural level it is apparent that patterns described in this vignette are consistent with those described throughout the period of the study, in other classes in the school, in classes taught by very senior teachers (e.g., McRobbie & Tobin, 1995), and in studies conducted at other grade levels, in other places, and at other times (e.g., Tobin & Gallagher, 1987). To understand why these patterns occur, we need to go beyond the actions of Morrell, his personal goals, and the manner in which he constructs the contexts in which he practices. Social forces shaped the enacted physics curriculum in such a way that the turbulence associated with Morrell's attempts to provide students with greater autonomy were barely discernible in a sea of events that conformed with traditional practices.

Warrants for Knowledge Claims

An important component of constructivist semantics is whether knowledge is regarded as viable, in that it enables an individual to meet his or her personal goals. In most instances, a learner can examine a knowledge claim in terms of its coherence with other knowledge regarded as viable, or the knowledge can be put to an empirical test. Alternatively, the knowledge can be accepted as true because it emanates from an authoritative source such as a scientist or a teacher, a textbook, or an institution. The following vignette involving Morrell and a student called Ian, and one of the researchers provides insights into the manner in which much of what students learn in physics is accepted on the basis of faith in the authoritative voice of science as represented by the teacher.

Ian was having trouble with a physics calculation on a revision sheet for the unit on work. This was a rare event for him because he was acknowledged as being the highest achieving physics student in the class.[1] The problem was the last in a bracket in which a force, a displacement, and the angle between the force and the displacement were given. On this occasion, the angle between the force and the displacement was 90°. Ian knew that application of the formula $W = f.d \cos 90°$ led to an answer of zero work being done, but he wanted to understand why this answer conflicted with his commonsense notion that some work was being done. The answer he knew to be correct made no sense to him. Ian was confused because the object was displaced. He reasoned that if it was displaced it must be moving, and if it was moving work must be done. Otherwise, he thought, it would stop moving.

Ian raised his hand, but Morrell did not notice. One of the researchers with a background in physics noticed Ian's raised hand, and although he was reluctant to intervene and possibly undermine the authority of the teacher, decided to provide assistance. Morrell looked up, and seeing that the researcher was providing Ian with assistance, continued to return equipment to the storage room.

"I know the answer is zero, but it makes no sense!" exclaimed Ian with a frustrated gesture toward his solution. It was clear to the researcher that Ian believed that since the object was moving, work must be done to sustain its motion. In an effort to resolve what appeared to be an inconsistency between Ian's knowledge of physics and what he knew from his everyday life experiences, the researcher asked Ian to identify all of the forces acting horizontally. At that moment, Morrell glanced over and decided to join the conversation.

Morrell quickly asserted his authority, ascertained what the problem was, and spoke to Ian about a parallel situation in which no work is done when an object is held motionless above the ground. Morrell gestured, holding his arm horizontally as if his hand held a heavy object, and then remarked that physics is weird sometimes. Morrell was, in effect, indicating to Ian that he should set aside his own commonsense knowledge in favor of the powerful voice of science. Even though Ian knew intuitively that the work done to maintain an object in motion was nonzero, he did not consider seriously that his own common sense was correct. Instead, he relied on a formula accepted as an article of faith, his own common sense subjugated with respect to the powerful voice of science. Furthermore, when Morrell shrugged, noting that science was sometimes weird, he reinforced a view that it is permissible to accept counterintuitive ideas without endeavoring to resolve inconsistencies.

Convinced that Ian could have resolved his perturbation quickly given the information that Newton's first law was relevant, the researcher suggested that except for friction, once an object was moving it would continue to move unless a force stopped it or retarded its progress. However, Morrell did not take up this issue, and returned to the task of storing equipment. Ian also was not convinced by the researcher's suggestion that Newton's law was applicable to a problem that he still framed in terms of a formula producing a result that made no sense. Later that day, Morrell mentioned to the researcher that the problem was not a good one and that perhaps the researcher was making more of it than the problem deserved.

The approach adopted by Morrell failed to deal with Ian's prior knowledge. Instead of asking Ian to represent the problem in terms of what he knew and then to deal with the viability of his knowledge claims, the teacher presented a situation that he found to be at odds with everyday experience. Ian was confused because the object was moving, and his intuition was that for something to move, work must be done. He did not think of the constant velocity scenario, and if he had he might not have had a problem at all. Nor did he think in terms of a moving object having energy and a capacity to do work. Even though he obviously had a strong mastery of the interrelationships between work, energy, kinetic energy, and potential energy, Ian was perplexed by the counterintuitive aspects of Newtonian motion.

Given that Ian knew more about physics than most students in the class, this vignette raises questions about the extent to which others in the class can give meaning to problems such as those involving work and energy transformations. There is little doubt that in the lessons we observed, the students all seemed capable of using the formulas with relative ease, and at the same time use physics to explain what was happening. What was not clear is the extent to which students were able to qualitatively give meaning to terms such as work, energy, force, velocity, and acceleration. When Morrell read this vignette, he responded in the following manner.

> The problem that Ian was facing was one that is counterintuitive for the majority of students I have encountered. The fact that Ian, being one of the brighter students in the class, had difficulty reconciling a relationship between Newton's first law, force, and work done says a lot about the blind-faith acceptance of this counterintuitive phenomenon by the majority of the other students, in that few other students questioned this particular problem. At the time when Ian was trying to resolve his dissonance with this example, possibly due to my inexperience as a teacher, I was unable to appreciate fully his dilemma and provide an adequate response.

Morrell's comment that the task might not have been a good one may have reflected his view that it was not the type of problem that would appear on an examination paper. What was likely to be assessed was a filter for Morrell on what to cover, what students should learn, and how much time to spend on given content. In contrast to what we might read in reports that advocate reform of science education (e.g., National Research Council, 1996), or hear from university-level science educators or state and district level administrators of curriculum, most science teachers would say that it is obvious that with just a few exceptions, the goals of most students who study science are not directly related to learning science. In many cases, students study science to enable them to gain entry to a particular university degree. In such circumstances, therefore, it is not surprising to find that students enrolled in physics to get the highest possible passing grade and thereby to satisfy prerequisites for entry to desirable programs of study at the university level. Accordingly, although students would no doubt like to understand physics, a higher goal was to pass examinations. Morrell commented that "This course is designed for kids to attain competency in order to do first-level tertiary courses." Thus, the belief that students had to be prepared for the next level of schooling was powerful for both Morrell and his students and reinforced a tendency to give priority to content coverage.

What is it about this community of practice that compels intelligent students such as Ian to accept the canons of science passively? We assert here that it is not characteristic of school science for students to be encouraged to call for evidence for the warrants of science or to demand alternative explanations to the academic tasks they complete. In a classroom where priority is given to covering the content of the curriculum and moving on before complete understandings have occurred, it is understandable why Ian and other students would regard science as sometimes being counterintuitive.

When should a learner accept on faith that particular knowledge is viable? It is obvious that not every learner of science can test the viability of every piece of information. At some time, a learner decides to accept the fact that someone has done an experiment or has proposed a theory, and that the knowledge is consistent with experimental results and other knowledge accepted within a scientific community as viable. In this example, Ian did not consider an ideal friction-free environment that was assumed in the problem he was endeavoring to solve. In effect, he had a qualitative answer that there was work being done, and a quantitative answer that the work done was zero. What may have prevented him from solving this problem was his conviction that the correct answer was zero. Instead of beginning with each solution as potentially viable and testing the viability of each, he may have classed his own solution as wrong and looked for assistance from a higher authority—in this case, the teacher. There is little or no doubt that Ian had the knowledge to solve this problem. What prevented him from so doing may have been his inclination to accept a voice of authority rather than to construct his own voice as an arbiter on issues of viability. The context was such that he did not know what knowledge was relevant. Morrell might have discussed the problem in terms of the kinetic energy of the moving object, the work done in sustaining its motion, and the capacity of the object to do work in the ideal situation of no friction and in the actual situation of an object sliding on a floor.

Knowledge, Power, and the Enacted Curriculum

The three vignettes presented here are linked by a level of coparticipation that varies in extent depending on the grain size used in the analysis. At one level, the approaches to teaching employed by Morrell are innovative and quite characteristic of what can be found in the myriad of reports that advocate the reform of science education. For example, Morrell uses constructivism as a referent for making sense of science teaching and for thinking about how he will enact the curriculum. Accordingly, he provides students with considerable autonomy and expresses a desire to relinquish power in circumstances where it is unusual for students to have power for extended periods of time. A clear example of this was in the activity that permitted students to design their own problems, solve them, and then act as peer tutors with respect to those problems. During the study, the tendency to provide students with autonomy was common. Despite this, the three vignettes illustrate that there was an ever-present dimension of physics as being elusive and beyond the grasp of everyday common sense. The discussion of relativity was almost like science fiction. It was interesting and constantly speculative. There was no effort to relate time dilation, for example, to phenomena that were a part of modern physics. Instead, examples were drawn from what we described as the *Star Trek* genre of events, and formulas were used as lynchpins for producing examples of the paradoxes of relativistic effects as the velocity of an object approached the speed of light. Warrants for the viability of relativity were not challenged, and the formula was taken as a given, a tool that was the basis for generating paradoxes.

The guillotine example highlights the problematic dimensions of a tendency to accept as viable propositions that make no sense. Having accepted paradoxes of relativity, it is plausible that students would also accept responses that seemed out of line with common sense if seemingly appropriate formulas were applied in algebraically correct ways. This is more likely to be the case when the calculated response is ordained as correct by the teacher. Thus, application of Newton's second law to the second part of the guillotine problem produced an answer that was a paradox, but because a well-known and widely applied formula was used in an algebraically correct manner that was accepted by the teacher, there was no evidence of the students arguing about the viability of the solution and endeavoring to find alternatives. The discursive characteristics of this transitional community seem to involve an uncritical acceptance of the voice of authority, as evidenced in canonical science and the say-so of the teacher.

The third vignette, involving Ian, clearly shows that concerns based on common sense are not taken seriously by either the students or the teacher. Both the teacher and the students, including Ian, were prepared to accept paradox as a part of their transitionary community. Since Ian belongs to a microcommunity populated by students who appear destined to become scientists, there is little doubt that he will carry with him the paradox and sort it out either as he reflects on the events of the lesson or in an out-of-school context. However, in terms of the classroom community and its transition to becoming sciencelike, the trends in the three vignettes suggest that this community at least will be characterized by tendencies to accept differences between common sense and canonical physics on the basis of the authority of physics. This tendency is not in the spirit of coparticipation, and disempowers students with respect to the development of relational and transformational understandings of physics (Tobin, in press). In making this judgment, it needs to be emphasized that the development of relational and transformational understandings was not a goal of Morrell's, and the tendency to disempower students becomes visible only when we select a grain size that examines the oral texts of the teacher and students. At a coarser grain size, it is apparent that students are encouraged to pursue understandings and coparticipate in peer groups. It might be argued that the issue of the relative disempowerment of students with respect to canonical physics was possible only because Morrell provided students autonomy and encouraged problem-based learning.

Morrell was respected as a teacher who had the responsibility of maintaining law and order within the classroom. However, these were highly motivated and responsible students who elected physics and wanted to succeed. When Morrell shed power by delegating responsibilities for certain tasks to students, they were willing to adopt new roles and participated with enthusiasm. There was ample evidence of students having considerable autonomy and the teacher adopting roles that were facilitative of learning through activities in which most of the participation was student initiated and controlled. From this perspective, it is apparent that the students had more power and Morrell had less power than typically is observed in science classrooms.

The students and the teacher employed a sciencelike discourse as they coparticipated in physics activities using a language that was negotiated and shared. However, in each of the three vignettes, solutions were accepted as viable even though they did not make sense to either the students or the teacher. The warrants for viability were acceptance of the authority of science rather than warrants based on coherence with other knowledge or with empirical tests. From this perspective, both the students and teacher were disempowered with respect to the social institution of science.

When scientific claims and everyday notions of common sense are not in accord, it seems desirable for an individual to resolve to settle the conflict either immediately or at a more convenient time. Empowerment is associated with an awareness that a knowledge claim does not make sense, and with having the discursive resources to resolve the conflict at an appropriate time. It is possible that a closer focus on coparticipation and the appropriation of a shared and negotiated language will assist in decreasing the incidence of examples of common sense being regarded as inferior to science as a way of knowing. Furthermore, if learning school science is regarded as a form of argument between different rational voices, then students might be encouraged to routinely compare their voices of common sense with the voice of science and to rationalize any discrepancies.

The research reported in this article was funded by a collaborative grant from the Australian Research Council.

Note

[1] Ian graduated from the school as valedictorian.

References

DiSessa, A.A. (1986). Artificial worlds and real experience. *Instructional Science, 14,* 207–227.

Driver, R., Guesne, E., & Tiberghien, A. (Eds.). (1985). *Children's ideas in science*. Philadelphia: Open University Press.

Erickson, F. (1986). Qualitative research on teaching. In M.C. Wittrock (Ed.). *Handbook of research on teaching* (3rd ed.) (pp. 119–161). New York: Macmillan.

Fairclough, N. (1992). *Discourse and social change*. London: Polity Press.

Galtung, J. (1980). *The true worlds: A transnational perspective*. New York: Free Press.

Gilbert, R. (1992). Louts and lads: Culture, power and theory in the analysis of schooling. *Education and Society, 10,* 73–83.

Gilbert, R., & Low, P. (1994). Discourse and power in education: Analysing institutional processes in schools. *Australian Educational Researcher, 21,* 1–24.

Guba, E., & Lincoln, Y.S. (1989). *Fourth generation evaluation*. Beverly Hills, CA: Sage.

Gulyas, C. (1994). Reflections on telling stories: A response to "resistance, revision and representation," *English Education, 26,* 189–194.

Hawkins, J. & Pea, R.D. (1987). Tools for bridging the cultures of everyday and scientific thinking. *Journal of Research in Science Teaching, 24,* 291–307.

McGinn, M.K., Roth, W.-M., Boutonné, S., & Woszczyna, C. (1995). The transformation of individual and collective knowledge in elementary science classrooms that are organized as knowledge-building communities. *Research in Science Education, 25,* 163–189.

McKibbin, C., Cooper, T., Arcodia, C., & Doig, S. (1995). *Teaching for effective learning* *in senior schooling (TELSS) project: Parents' perceptions of an inner city secondary school*. (Tech. Rep. No. 4). Kelvin Grove, Queensland, Australia: Queensland University of Technology.

McRobbie, C.J., & Tobin, K. (1995). Restraints to reform: The congruence of teacher and student actions in a chemistry classroom. *Journal of Research in Science Teaching, 32,* 373–385.

National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.

Roth, W.-M. (1995). *Authentic school science: Knowing and learning in open-inquiry science laboratories*. Dordrecht: Kluwer Academic.

Schön, D. (1985). *The design studio*. London: RIBA Publications Ltd.

Tobin, K. (in press). Social constructivist perspectives on the teaching of science. In H. Waxman, H. Walberg, & J. McCutchan (Eds.). *New direction for research on teaching*. Berkeley, CA: McCutchan.

Tobin, K., & Gallagher, J.J. (1987). The role of target students in the science classroom. *Journal of Research in Science Teaching, 24,* 61–75.

Tobin, K., Kahle, J.B., & Fraser, B.J. (Eds.). (1990). *Windows into science classrooms: Problems associated with higher-level learning.* London: Falmer Press.

Tobin, K., & LaMaster, S. (1995). Relationships between metaphors, beliefs and actions in a context of science curriculum change. *Journal of Research in Science Teaching, 32,* 225–242.

Tobin, K., & McRobbie, C.J. (1996a). Cultural myths as restraints to the enacted science curriculum. *Science Education, 80,* 223–241.

Tobin, K., & McRobbie, C.J. (1996b). Significance of limited English proficiency and cultural capital to the performance in science of Chinese-Australians. *Journal of Research in Science Teaching, 33,* 265–282.

Tobin, K., Tippins, D.J., & Hook, K.S. (1994). Referents for changing a science curriculum: A case study of one teacher's change in beliefs. *Science & Education, 3,* 245–264.

van Dijk, T. (1993). Principles of discourse analysis. *Discourse and Society, 4,* 249–283.