THE TRANSFORMATION OF INDIVIDUAL AND COLLECTIVE KNOWLEDGE IN ELEMENTARY SCIENCE CLASSROOMS THAT ARE ORGANIZED AS KNOWLEDGE-BUILDING COMMUNITIES

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Abstract

This study was designed to address two purposes. First, we wanted to test working hypotheses derived from previous studies about the transformation of individual and collective knowledge in elementary classrooms. Second, we attempted to understand the degree to which "ownership" was an appropriate concept to understand the process of learning in science classrooms. Over a four-month period, we collected extensive data in a Grade 6/7 classroom studying simple machines. As in our previous studies we found that (a) conceptual and material resources were readily shared among students, and (b) tool-related practices were appropriated as newcomers participated with more competent others (peers and teachers) in the pursuit of student-framed goals. We also found that for discursive change ("learning") at the classroom level to occur, it appeared more important whether a new language game was closely related to students' previous language games than who actually proposed the new language game (teacher or student). Implications are drawn for the design of science curricula and classroom activities.

> Both pedagogy and design are still tightly bound by rationalist, symbol-manipulating, problem-solving assumptions that hold knowledge to be a property of individuals. Pedagogy still concentrates on the individual and individual performance, even though most work is ultimately collaborative and highly social. (Brown & Duguid, 1992, p. 171)

Ample research in the recent past has shown that daily human practices in scientific laboratories and just plain everyday life are in fundamental ways socially situated (Latour, 1987; Lave & Wenger, 1991). Particular groups distinguish themselves from others in the specificity of their practices; in their differences, these groups constitute communities of practice. Newcomers to these communities of practice learn much of what constitutes canonical knowledge (commonly accepted and shared knowledge) from more experienced and competent old-timers by engaging in these practices; but, they also learn in important ways from each other by sharing stories of successes and failures. These notions are further explicated in the following example from our previous research in a Grade 4/5 classroom where children designed a variety of structures (towers, bridges, domes) (Roth, in press-a,b,c).

Tim was one of the first students in the class to bring a glue gun from home. Clare and Shelly, as many others in the classroom, had never used a glue gun before. At first, Tim refused to lend the glue gun to the two girls who worked next to him; however, he showed them how to use this tool in the context of their work, how to bring the nozzle close to the materials or how to pull it away when the glue bead was to be terminated. Then, after several demonstrations and exasperated by their repeated requests, he let the girls use the glue gun. Clare made her first joints under Tim's supervision. Later, once satisfied that Clare used the glue gun properly, Tim no longer oversaw their work. Once Clare used the tool, Shelly also wanted to learn how to use it. At first, Clare modeled glue gun use as Tim had previously done it. Under Clare's supervision, Shelly then made her first attempts.

In this example, we see the beginning of a community of practice. Operating a glue gun is a practice. This practice can be learned by "apprenticing" with a competent user, or, in Lave and Wenger's (1991) terms, by participating in a legitimate peripheral way. Tim (as a few other students) was the old-timer, Clare and Shelly the newcomers. In this way, and without the influence of the teacher, the classroom community transformed itself based on practices already socially and materially situated in its own ranks. Because of its focus on individual performance, most science education has not realized or made use of the potential that lies in the social nature of knowing and learning. The present study is part of our research program designed to develop an understanding for the emergence and transformation of communities of practice in science classrooms.

In our studies, we are concerned with different kinds of knowledge, resources and practices (Roth, in press-a, b, c; Roth & Bowen, 1995). We distinguish resources—which include all those things that people need for their practices, facts, artifacts, tools, ideas, etc.—from practices. Tool-related practices are all those human practices that involve manipulating tools and deploying materials. Thus, using glue guns as Tim, Clare, and Shelly in the previous example, and using hammers to drive in nails, computers to do a regression analysis, or pulleys to configure an experiment count among tool-related practices. On the other hand, doing a conceptual analysis of a pulley system, configuring drawings to analyze various ways of using a pulley, or providing a verbal description and explanation of the forces in a pulley system are discursive practices (throughout this article, we use "discourse practices" and "language games" synonymously). These categories allow us to distinguish between knowing the name of a practice such as "Lana's law" for the product moment rule to solve balance beam problems (which is a resource), and deploying the rule to get the problems done (discursive practice)--this distinction presents the core of our analyses reported in this study. These categories are consistent with our belief that "skills" (tool-related practices) and "conceptual knowledge" (discursive practices, language games) do not stand in an inferior / superior relationship to each other. This balance between tool-related and discursive practices is consistent with recent analyses of scientists' laboratory work that have illustrated the interdependent nature of tool-related practices, discursive practices, and the world as we know it (Gooding, 1992).

As a result of a previous ethnography in a Grade 4/5 classroom in which students designed various structures, we believed that the ease with which a community accepts a resource or practice was a function of the ownership which we saw with who originated this knowledge (Roth, in press-b, c). For example, children rapidly shared resources (facts and artifacts). In some instances, their community was transformed within a lesson or two, so that many members were in the possession of a specific artifact (e.g., a Canadian flag to adorn a structure) or knew the name of a building technique (e.g., students could tell teachers, on cue, that triangular braces are building elements that stabilize a structure). On the other hand, discursive practices were much less widely appropriated. Thus, even after six weeks, few students had adopted the practice of using triangular braces as a priori design features.

This study was conducted for two purposes. First, it was to serve as a "confirmatory" ethnography. We wanted to test whether and which aspects of previous descriptions and explanations about the transformation of knowledge in a community--as described in the Tim / Clare / Shelly case and the previous paragraph--would be confirmed or disconfirmed; that is, transported into a new situation with students of different ages, studying a different curriculum, and with different teachers, but within the same school setting. The second major purpose was to unconfound knowledge type (resource versus discursive practice) and origin (student versus teacher) to see whether ownership provides an appropriate explanatory concept for differential appropriation of knowledge in a community, as we previously conjectured.

Research Design

Setting

This study was conducted in a Grade 6/7 classroom at a public elementary school, Mountain Elementary, in an urban area of Western Canada. The staff at this school had made a collective commitment to improve science teaching. An anonymous survey in Grades 4 through 7 suggested that most students wanted more student-centered, hands-on science. While teachers were willing to change, they felt a need for outside help and consultation. Our research team agreed to facilitate teacher inservice (as outside facilitators to teacher-organized professional development days) and in-class teaching (by assisting in planning science lessons and through team-teaching) in exchange for the opportunity to document the associated changes of science teaching and learning.

Participants

Teachers

In one of the arrangements with the teachers at Mountain Elementary, one of the authors (WMR) taught a four-month science on simple machines. With graduate degrees in physics and in science education taught the unit; he had 12 years of teaching experience, two at the same grade 6/7 level, and had team-taught a similar 10-week unit on simple machines during the preceding school year to a Grade 7 French immersion class. He designed and planned all activities with feedback from Cam, the homeroom teacher who taught English and social studies.

Cam was also in the class to assist in dealing with interpersonal conflicts that arose among students. He previously taught social studies at a local high school and just recently had become vice principal at Mountain Elementary. Cam had a graduate degree in counseling and 21 years of teaching experience, but this was his first year teaching at the grade 6/7 level. Furthermore, he had never taught science before but felt that his students should not suffer because of this. Cam therefore approached WMR and asked if it was possible that an experienced science teacher taught a unit in which he could learn by observing and, to a limited degree, by participating.

Students

There were 10 Grade 6 (5 boys, 5 girls) and 16 Grade 7 students (7 boys, 9 girls); one of the Grade 7 boys left mid-way through the unit. Four of the students were classified as learning disabled (in one case paired with Attention Deficit Hyperactive Disorder), one boy had muscular dystrophy and associated physical and cognitive impediments to do required work in his regular classes. Two Grade 7 girls experienced some difficulties because English was their second language. There were also three Grade 7 students who did not relate to other students, so that others categorically refused to work with them. Two students (one belonging to the previous group with whom others refused to work) set themselves apart from other students by not signing the set of rules established by the class to govern interactions.

In contrast to other classes in this school, the students were taught by seven different teachers—one for each of English and social studies, science, mathematics and spelling, French, physical education, art, and (for six students only) school band practice. Observations of lessons taught by different teachers revealed that this led to considerable variations in classroom norms and associated differences in student behavior.

This class was very difficult to teach. Both teachers pointed out during debriefing sessions, that this was the most difficult assignment in their experience. In part, these difficulties appeared to arise from widely varying competencies to participate in regular activities. To a great extent, these problems arose from dysfunctional social dynamics present in this class for almost four years. Particularly, the two students who did not sign the classroom norms frequently interfered with other students' attempts to participate in ongoing activities.

Past research has identified frequent grade and gender differences in science achievement (for a review see German, 1994). Such differences did not exist in the present classroom after instruction. A 2 (boys, girls) x 2 (Grade 6, Grade 7) MANOVA using students' science marks on the final project, the written examination, and discursive competence during a debriefing session as dependent variables revealed no statistically detectable main effects or interactions. Five of nine students identified by Cam as cognitively or socially disadvantaged achieved in (four students) or near (one student) the top quartile.

Simple Machines Unit

Curriculum

We developed the unit based on the notion of learning as an increasing generation of and participation in tool-related practices and discursive practices (language games). Our main focus was on the development of students' language games related to simple machines. However, we did not want just any language games to emerge, but were interested in fostering those that showed some resemblance to language games in scientific communities on similar topics. We operated under the assumption that any founded language game about simple machines had to develop from students' current discourse. By choosing diagrams and associated physical models that were relevant in other domains of discourse (e.g., physics), we set the stage for producing, maintaining, and developing new language games to handle these segments of the world, that is, diagrams and physical models, more appropriately.

The simple machines unit lasted from the beginning of October to the end of January for a total of 36 lessons. Normally, there were two 70-minute and one 55-minute lessons per week. We began the unit with a whole-class discussion of machines and their purposes, followed by a specific example of a pulley mounted in different configurations (in one configuration, the pulley was fixed and simply change direction of force, but provided no mechanical advantage; in the other configuration, the pulley was moveable and provided a mechanical advantage of about 2). After that, we followed the same pattern of activities. First, students took about three lessons to design machines ("designing," for a series of complex reasons explicated elsewhere [Roth, in press-a], includes making drawings and constructing working models). We split the subsequent three to four lessons into two parts. During the first part of a lesson, WMR led whole-class conversations about conceptual issues relating to simple machines, or small groups of students completed investigations and/or recorded their ideas on previously discussed topics. During the second part of a lesson, students presented their machines in whole-class sessions and directed sense-making conversations.

Activities

We designed whole-class conversations around teacher-designed and -constructed simple machines and associated diagrams in the form of overhead transparencies (pulleys, block and tackle, balanced lever, second and third class levers, inclined plane, work, energy, mechanical advantage) (about 25% of the unit). For example, WMR moderated a class discussion about two different ways of setting up a pulley. In one, the effort remained the same, in the other, the effort was cut in half. The purpose of the lesson was for students to develop a language game, descriptions and explanations, of all forces acting in the system, and to measure these forces. In the case of each force, WMR asked students to predict the forces, one force at a time, operating at various points in the system. After a number of students (about eight to ten) had made their predictions, and after tallying the commitments of other students, the teacher involved students seated closely to the pulley in measuring the forces ("measuring" is a tool-related practice, the Newton meter itself, used to measre the force, is a resource). The magnitude of each force, along with student predictions, was recorded on an overhead transparency displaying key features of the system. WMR subsequently asked students to explain the outcome. Some of these discussions followed students' own exploratory activities with the device (balanced lever, second and third class levers), while others, because of time constraints, were treated in whole-class sessions only (pulley, block and tackle, inclined plane including work and energy).

During whole-class conversations around student-designed artifacts, students presented the machines they designed in whole-class sessions which included opportunities for other students to ask questions or make comments (about 30% of the unit). Presenting students directed these conversations. Teachers only intervened to restart halted conversations or mediate conflicts or other communicative problems. This activity structure was based on research findings that students who are required to elaborate, explain, or defend their own ideas tend to evaluate and integrate knowledge in new ways (Hatano & Inagaki, 1987); it also seems to encourage changing language games--in other words learning--or at least provide opportunities to do so (Roth, 1995b; Roth & Roychoudhury, 1992). We assumed that students were more likely to engage in elaborating, explaining, and defending when the questions and critique came from peers because they were framed within the same language game. In this way, students could take greater responsibilities for their participation and feel in charge of classroom activities.

We included in our lessons, small group investigations and reflections organized around simple machines (equal arm balances, second and third class levers), written instructions, and summary sheets designed by the teacher to highlight canonical concerns (about 15% of the unit). We included these activities to provide students with opportunities to manipulate and explore simple machines, develop familiarity, and come up with tentative explanations of the machines' functioning. Students also had to negotiate differences in understanding, because each group was required to produce one agreed-upon answer. That is, students had opportunities to develop, experiment with, and participate in language games before going public and presenting them to the whole class and the teacher. After students completed their activities, the same diagrams and models served as focal points in teacher-directed whole-class conversations. Thus, this activity structure resembled that used in elementary mathematics classrooms where students are first provided with opportunities to solve problems on their own and subsequently engaged in whole class conversations (Cobb, Wood, Yackel, Nicholls, Wheatley, Trigatti, & Perlwitz, 1991; Lampert, 1986).

Working in small groups, students designed and constructed models of machines that sufficed a number of teacher-specified or classroom-negotiated conditions (about 30% of the unit). Over the course of the unit, students designed four hand-powered machines. The first three machines were to lift loads, move loads over a long distance, and move loads by means of a self-propelling mechanism. In the fourth machine, students were to combine a minimum of four processes, two of which had to be based on the simple machines discussed in the unit. Artifact design is an important learning environment that allows learning-in-practice as students pursue goals of their own interests. However, design tasks are not well suited for transmitting specific facts, but for participating in activities central to design practice (designing and testing artifacts, generating hypotheses, making presentations, describing systems, etc.) (Harel, 1991; Kafai, 1994). Because of the generally unstructured nature of the tasks, students have opportunities to engage in specifying goals, framing troubles and breakdowns in the pursuit of these goals, and finding resolutions that allow a continuation of the main activities. Furthermore, we knew from our previous research that, in open-design classroom communities, new language games evolve and circulate among student members (Roth, in press-b, c).

Making it Work

We were interested in designing a unit that teachers could do without great expenditures. Thus, we built individual or class sets of artifacts with materials available from hardware and office supply stores (including nuts, stripping, elastics, glue sticks, masking tape, paper clips, and grommets for fastening tarpaulin [for pulleys]). Students brought scrap materials and tools from home for their constructions. We provided one set of simple tools including a hammer, drill, saw, glue gun, Exacto knife, and C-clamps. We set aside two work places: one large table that we protected with sheets of 3/4" plywood, and a small table across the room for operating the glue gun.

For the students, teaching and learning in this science unit differed from that in their other subjects. Their other teachers emphasized traditional teaching with a focus on facts and right answers. Students listened to a presenting teacher, completed routine seat work, mathematics drills, fill in the blanks in social studies, or recited facts. Their tests were factually oriented ("Define perimeter" "The capital of Nova Scotia is ... Halifax or Moncton?"). Teachers took major responsibilities for structuring students' work and organizing their notebooks (placement of pages, location of specific entries such as title or date on each page).

In contrast to their other classes, students felt (especially in the beginning) that this science unit presented too great a challenge. Students thought that the teacher (a) had unwarranted expectations, (b) permitted too many students to voice their ideas, (c) did not give them enough time, (d) did not immediately give them right answers ("If we're asking you a question about how we can make this work or something, you could give us an answer instead of asking us."), and (e) gave too much homework ("People usually don't want to do it after school or at home because they have enough homework as it is.").

With time, many students appeared to adjust and no longer expected to be given right answers; they participated to varying degrees in whole class conversations, and many seemed enthusiastic about the construction activities. We negotiated time allotments with students, and abandoned asking them to establish their own glossaries outside class time. In the end, Cam felt that the Grade 6 students who had less prior science experience adjusted much better than the Grade 7 students. One of the most audible changes in classroom conversations was the fact that students increasingly included explanations and justifications for their answers. For example, when asked for an hypothesis about the magnitude of a tension, students initially stated a number. WMR followed such laconic responses by "Because?". Over time, students increasingly included justifications on their own, "I agree (disagree) with ...., because ....." or "I think it's ... because ..."

Data Sources

Besides WMR, the other three authors were participant observers throughout the study. As a team, we videotaped all lessons continuously using two cameras. During whole class activities, the second camera served as back-up and to record student utterances as completely as possible. In addition, we operated two audiotape recorders to capture (a) presenting students' utterances, (b) teacher-student interactions, and (c) interviews conducted in the setting as students worked on their design projects.

In our audio and videotaping, we did not ask students to remain at one place, or to reduce the noise they made, although this would have produced better video and sound quality. To make such changes would have been counterproductive to observing knowing and learning as they occur in regular classrooms (Roth, in press-c). As a result of our ontological commitments to the situatedness of plans, actions, and more generally, all cognition, we used the precepts of Interaction Analysis for taping events, gestures, actions, social configurations, physical arrangements, and artifacts (Jordan & Henderson, 1995).

In addition to the taped records, we conducted ethnographic observations documented in fieldnotes and as photographs. After each lesson, the teacher-researcher debriefed with at least one other member of the research team; these debriefings were also documented as fieldnotes. Based on these fieldnotes and our experience during transcription, we prepared theoretical fieldnotes which entered the database. The entire curriculum development effort, all curricular materials, and the artifacts used during teaching became part of the database. We videotaped all curriculum planning meetings and interviews (designed to solicit information about students and the classroom situation) with Cam. Finally, we conducted ethnographic fieldwork in the class during students' other subjects and informal interviews with the respective teachers.

Prior to and at the end of the unit, we tested students in a number of ways. First, students prepared a semantic map of all the ideas they associated with simple machines. Then, they responded to questions about three instances that illustrated the application of levers, pulleys, and inclined planes. We completed the pretest phase by interviewing 13 students about their ideas on simple machines, requesting elaborations of their written answers, and observing their qualitative and quantitative responses to equal arm balance problems. The posttest was designed in a similar fashion, with the difference that we invited pairs of students to talk about their answers on the test and to model solutions to three practical problems. With many student groups, these interviews were more like conversations among students. By debriefing students in pairs, we dealt with the problematic issue of ecological validity: during the lessons, our emphasis was on tool-related and discursive practices embedded in a social matrix. Therefore, the posttest situation, if it was to have any ecological validity, needed to reproduce the social situation to some extent. Some students also felt that debriefing in pairs better reflected their learning in this class ("It's much better with a partner. We worked on most stuff together, and although you sometimes argue, it's easier with two"). All written work became part of the database as did the videotaped debriefings and their transcripts.

Our entire team transcribed to make the conversations available for analysis and as feedback to direct further curriculum design and planning. Typical for design experiments (A. Brown, 1992), our observations and interpretations during data collection directed the subsequent design of teaching materials, social configurations, physical arrangements, temporal organization of activities, and time allotments.

Data Analysis

This study was conducted as a "confirmatory ethnography." One of its two aims was to test the descriptions and explanations derived from an ethnography in a different classroom with younger students studying a different unit (details are provided with the results of the present investigation). Thus, we tested whether our working hypotheses were "transferable" (Lincoln & Guba, 1989) to a new context. Much like confirmatory factor analysis, "confirmatory ethnography" sets out to test whether constructs derived in one situation adequately model phenomena in another. Because we are aware of the well-known phenomenon of confirmatory bias, we tried to find situations that could not be modeled by our previous understandings. Our efforts in conducting the confirmatory ethnography were facilitated because we met three key requirements required of qualitative research in this respect: (a) two of the team members had participated in the earlier study and thus knew both contexts, a pre-condition for all replication attempts in naturalistic research; (b) thick description existed for the initial context in the form of extensive video- and field note-based data corpus; and (c) two new team members brought different perspectives which helped to guard against confirmatory bias (Lincoln & Guba, 1985).

According to precepts of Interaction Analysis on the basis of videotaped data, our formal data analyses were conducted in sessions with two to four authors (Jordan & Henderson, 1995; Suchman & Trigg, 1991). We played the videotapes, stopping and replaying as often as needed and whenever a team member noted something remarkable. In this way, we also ascertained transcript accuracy as to utterances, overlaps, emphases, and so on. When we isolated a significant event, we searched the entire database (not just videotapes) to see if the event represented a class of events. These analysis sessions were taped and recorded in fieldnotes; a flip chart was used to provide a permanent record of notes and drawings made during the meetings. Tapes, fieldnotes, and flip charts all entered the database.

Resources and Tool-Related Practices

A previous ethnography in a Grade 4/5 classroom studying a civil engineering unit showed that when students knew what others were doing, they could adjust their actions, redefine their problems, extend the original boundary conditions on their tasks, utilize new materials, or build on explanations and stories they learned from their peers (Roth, in press-b, c). Locations where students gathered closely were ideal sites for such learning to occur; whole-class sessions constituted other situations in which information could be exchanged easily and where students could find out about others' work and ideas. We further illustrated how the physical classroom, individual students, and the classroom community were transformed with the increased availability of glue guns and the appropriation of associated gluing practices. We described the appropriation of a tool-related practice as a trajectory from limited peripheral participation to full participation in the practice. In this process, newcomers learned by working at the elbows of their more competent peers. This process involved transformations associated with the embodiment of practices in individuals. The purpose of this section is to illustrate the extent to which our previous descriptions are applicable to the present study in a Grade 6/7 classroom studying simple machines with a different teacher.

Resources

Resources available in the classroom include all the materials and tools students used in their constructions, the artifacts produced by students and by the teacher, the labels students used to discuss their work, and the ideas that stimulated their actions throughout the course.[1] In fact, resources are the materials that make tool-related and discursive practices possible. For example, the labels students used to index concepts or artifacts such as "Lana's Law," "pulley A," and "pulley B" were essential to students' discursive practices (we will discuss these labels and their relationships to discursive practices in a later section). As in our Grade 4/5 class studying civil engineering, we found that, with a few exceptions, resources were shared relatively easily and frequently in the classroom. To illustrate this finding, we highlight here the case for tools and materials and for ideas.[2]

Tools and Materials

Prevalence of sharing. We observed numerous instances where students borrowed or lent materials and tools. "Can I borrow…?" and "Does anybody have…?" were common pleas during construction periods. If students had the requested item and did not need it for their own project, they typically gave it to a peer. In other instances trades were made. For example, while working on the first project, Brenda and Sharon traded a piece of wood for a piece of metal from Lana, and then later traded a small hook for a longer hook, also from Lana. Students who did not have the requested item often provided suggestions as to where to get the desired item or a substitute. In fact, sharing materials and tools was such a commonplace aspect of the classroom community that on one occasion, a disagreement broke out between Andre and Jon because Jon was unwilling to relinquish a needed piece of wood. Andre was upset because Jon refused to share, something he recognized as a required aspect of the community.

In this community, adults (teachers and participant observers) frequently served as brokers between students, bringing into contact those with similar problems, or those who had a solution to the problem of another. For example, during the first construction day, Matt went around the room looking for a pulley.[3]

WMR: How can we deal with the problem that Matt has, Matt needs a pulley, yeah?
Lana: What Amy and I (??). We're making a pulley.
WMR: So, you're making a pulley. Matt did you hear? One possibility is to make a pulley.

After WMR had mediated this connection between the two students, Lana explained to Matt how she made a pulley, a solution he too could use.

Refusals to share. Despite the prevalence of sharing, there were also instances where students refused to share. In some cases, such refusals stemmed from pre-existing conflicts between members of this community. However, for one pair of students, Jon and Dave, requests to share led to frequent interruptions of their own work, so that they became less willing to share later in the unit. At the beginning of the unit, Jon and Dave (who always worked on their projects together) were central suppliers of tools and materials to their classmates. Unlike other groups, they brought a fairly complete set of tools and materials at the beginning of the unit (hammer, drill, saw, glue gun, nails, screws, wood, etc.). Other students recognized this, and often went to them for support and to borrow resources. Jon became more and more distressed by the disruptions caused by these requests, "Dave and I have been working and people just came over and said 'Oh can I have a nail or stuff like that,' it takes time off us for our project." These disruptions are clearly evidenced throughout the database. In one specific example, in a two-minute span, Dave and Jon were interrupted by five students with requests to borrow stuff, plus one other off-task interruption. By the final project, they (along with their partner Marilyn) resorted to keeping their tools hidden and building at home to minimize such disruptions. In this way, they maintained a monopoly on their tools, inhibiting the diffusion of tool-related practices evidenced in our earlier ethnography.

Ideas

Consistent with our earlier ethnography, we found that ideas diffused rapidly throughout the classroom community, but with occasional conflicts over who was the originator or inventor of an idea. Students regularly checked with their peers whether their own ideas conformed with task specifications or what other students were doing. This sharing of ideas helped students regulate their own behavior and provided seeds of inspiration for their projects. For example, while designing their first project, Alain and Shaun disagreed about the appropriate complexity. Shaun turned to Brenda and Sharon, who sat at the neighboring desk, to find out what they did. Shaun reported back to Alain, "See, not just a pulley and rope." After this confirmation, Alain and Shaun proceeded to construct individual projects that involved more than "just a pulley and rope."

For the third project, students seemed to be initially confused by the self-propelled requirement. During the introductory discussion, Jay explained how an elastic could be used to build a self-propelled machine, but few students seemed to understand or accept the description of self-propelling. During the following lesson (planning), more students constructed an understanding of "self-propelling," but typically only after first designing a machine that was not self-propelled. On the third day of the project (construction), students started building self-propelled machines. Over the subsequent construction periods, four students built cars propelled by an elastic wrapped around the axle, as Jay had described (although they did not necessarily associate this idea with Jay's earlier description). In the same way, another idea was adopted by seven students to propel paddle boats. Jon, Dave, and Amy were the first group to discuss this idea, drawing the idea from Jon's cub book. Part way through the class period, Andre borrowed the book and he and Kevin started work on a paddle boat, as well. During Kevin and Andre's presentation, Marilyn asked where they got their idea. Another student responded "From Dave and Jon" Andre disagreed, arguing that he got the idea from "Movies, boring old movies." In most cases, although ideas were shared, the projects were not identical. Students transformed and further developed what existed previously. This was particularly apparent in those situations where students asked permission for a second try. For example, Celia and Julia build a paddle wheeler with eight independent paddles; Nana's paddle wheeler was operating so well that it established a new distance record; and Ellice's cart, modeled on Jay's idea, made use of a stronger elastic and a better suspension, beating the previous distance record by a factor of three.

For the final project, students also designed and built a number of similar projects. Many students used two basic ideas as resources for planning their own projects: Five projects were designed to extinguish a candle and three to feed a cat (the other three projects were designed to pour juice, light a candle, and water a plant). These two most popular ideas, "a machine to extinguish candles" and "cat feeder" were shown in a brief video of another class' final projects which students viewed during the initial planning day (the video also presented a third idea, not adopted by anyone in this classroom, to switch on a light). This video may have provided the initial source of inspiration for these projects, but each project was unique, rather than a close copy of other available models (on the video or in this classroom).

Tool-Related Practices

The construction activities in this classroom provided students with ample opportunities to learn about and use a number of tools including saws, drills, hammers, screwdrivers, glue guns, an Exacto knife, and C-clamps. For many students, these opportunities provided initial encounters with these tools. Learning to manipulate levers, pulleys, and other simple machines were also essential tool-related practices in this classroom. We found that students' developing tool-related practices paralleled the descriptions we have provided from our Grade 4/5 civil engineering classroom.

Critical to students' developing tool-related practices was the availability of tools. As we have described, there were limited resources in the classroom. Students who did not have available tools had to borrow them, or improvise with other resources. Initially, Dave and Jon had a complete set of tools which they shared with and demonstrated to other students. However, unlike in the Grade 4/5 community, Dave and Jon did not give up their monopoly on these tools, and later in the unit decided instead to make their tools unavailable to other students to limit disruptions to their own work.

Without access to the tools, students were unable to develop tool-related practices. For example, students were not allowed to use the Exacto knife without teacher permission and supervision, so there were few opportunities for students to, as Bakhtin (1981) would probably say, populate this practice with their own intentions. In this way, Exacto knife usage did not become part of the community. On the other hand, hammers (and substitute hammers, e.g., liquid paper bottles, glue sticks, screwdriver handles, pieces of wood, etc.) were freely available, and all students had opportunities to engage in hammering.

With the scarcity of tools, students were required to gather around the sources. The major sources were at the drilling/sawing work area, the glue gun station, and, at the beginning of the unit, Dave and Jon's work space. There were high concentrations of students at these locations which provided enhanced opportunities for students to learn from each other about their ideas and how to use tools. The electrical outlets, the work tables (in part determined by the electrical outlets), the water station, the porch (where more dangerous activities could be conducted, which was especially important for the final project), and the cloak room (where students could set up away from others to test big projects) imposed conditions for specific physical orientation of the members within the community.

Students learned many practices from each other. Some were more experienced, old-timers in using specific tools, from whom newcomers learned. Old-timers frequently modeled tool-use and subsequently observed and scaffolded newcomers' first attempts. For example, while working on their second project, Dave and Jon needed to cut each of two large piece of wood into three smaller pieces. They decided this would be best done on the back steps of the classroom, and requested permission to do so. First, Jon stood on the board while Dave, the owner of the saw and an old-timer in the sawing practice, operated the saw. After completing the necessary cuts for the first board, the two boys traded tasks with Jon sawing and Dave holding. Jon was also familiar with sawing, but was not as highly skilled as Dave. Dave not only helped Jon learn by participating in practice, but served as an old-timer in tool use for the classroom community more generally. Thus, students from other groups learned by watching Dave and working under his supervision before using tools on their own. In the following episode, Alain learned some important lessons about drills and how to use them. Other students also participated more peripherally, as concerned by-standers, in the ongoing activity.

<u>Episode 1</u>

Dave and Jon observe Alain who has borrowed their drill. Alain drills his piece of wood at the end of their desk. Dave realizes that Alain is operating the drill inappropriately:

Dave:	Watch the desk. You're going the wrong way (he joins Alain)
Jon:	You're going the wrong way. Flip the switch.
Randy:	Oh my god, he's going the wrong way.
Alain:	What? (Dave flips the reverse switch on the drill.)
Randy:	That was going backwards. It's a drill. See now it works.

Jon wants Dave to let Alain work on his own, but Dave continues to observe the newcomer. Jon joins, and when Alain experiences trouble, Dave takes the tool and shows how to drill a hole. Todd and Kevin join the group, also observing Dave drill a hole.

Here, Dave provided support for Alain's efforts at using the drill, and, when necessary, did some of the drilling for him. In this, Dave combined two types of activity.

He did the required job of drilling a hole, and at the same time, provided a demonstration. Jon and Randy provided advice and warnings. Such activity was commonplace in our classroom.

Teachers also contributed to the emergence and transformation of the classroom community in available tool-related practices. They provided instruction and advice, modeled practices, and oversaw students' first attempts in tool-related practices. For example, WMR frequently modeled techniques of sawing or drilling. He then provided opportunities for students to saw or drill under his supervision. Sometimes, he provided additional comments to the students on how to improve their technique, and then let them continue on their own. All these examples had in common that students learned to use a tool not a priori, but just-in-time, because they needed it for completing the project they had planned.

In the context of, and interacting with, the shared and sharing of resources and tool-related practices, students developed a new language game on the topic of simple machines. The transformation and appropriation of these discursive practices is the topic of the next section.

Transformation and Appropriation of Discursive Practices

In the previous section, we illustrated those transformations of a classroom community that confirmed our previous understandings. Here, we focus on the second purpose of our study, to clarify the relationship between inventing a resource or practice, and the rate with which it was adopted by the classroom community. Our previous work appeared to suggest that knowledge introduced by the teacher was less appropriated by the community than knowledge introduced by a student (Roth, in press-c). We conjectured that knowledge introduced by students allows peers a greater degree of ownership than knowledge introduced by the teacher. However, the previous study confounded source of introduction and type of knowledge. That is, discursive practices introduced to the community by the teacher were less rapidly adopted than resources introduced by students.

Two case studies are used to follow the transformation of knowledge available in the classroom community. Although students invented a series of laws or rules to describe patterns of the behavior of simple machines, the associated discursive practices did not become widely available. The labels introduced by the teacher ("Lana's law," "Randy's rule," "Alain's rule," "Shaun's catapult lever") were readily available (as was the label "triangles" in the Grade 4/5 classroom). The teacher-researcher labeled the students' inventions to associate them with particular individuals, and to characterize the ideas' origins within the student community rather than with the teacher. This labeling was intended to facilitate the transformation of knowledge thought to reside in ownership or come from inventing. These labels, and the postings describing them, were readily available as resources to community members, unlike the accompanying discursive practices. On the other hand, the notion of mechanical advantage, though introduced to the discourse by the teacher, was readily accepted and became a major form of talking in the classroom community.

Language Games Invented by Students: Lana's Law

There were repeated situations in which students formulated a mathematical "law" or "rule" that could be used to answer questions related to the functioning of simple machines. For example, Lana proposed a product moment rule and Randy a ratio rule to equilibrate an equal arm balance; Alain suggested a ratio rule for determining the relationship between effort and length of an incline; and Shaun suggested that a third class lever functioned like a "catapult." Because we thought that knowledge constructed by and associated with students would be more likely to transform the classroom community, the teacher explicitly labeled these rules with the originating students' names. They were "published" on the bulletin board as summaries of the whole-class discussion —essentially the teacher-produced transparencies that had served as foci of whole-class conversations complete with student contributions, tagged with contributors' names. These laws were celebrated as the class's accomplishments, and the teacher did not attempt to "teach" more than what students in the guided whole-class discussion formulated. In a sense, this study placed similar values on students' curriculum oriented language games as teachers had done in certain celebrated classroom studies in mathematics (Cobb, Wood, Yackel, Nicholls, Wheatley, Trigatti, & Perlwitz, 1991; Lampert, 1986). However, we wanted more than just a diverse set of answers; we were interested in the appropriation of one student's language game by the classroom community.

<u>Initial Practice</u>

Similar to the studies in mathematics learning, we began our investigation of levers with a student-centered activity. In groups of two or three, students were asked to do 12 problems in which pairs of weights had to be balanced--the distance of one of the weights to the fulcrum was given. After completing the problems, students were asked to write down any patterns they had observed. The teacher then brought the students together for a whole-class conversation to have students generate a summary--assisted by the teacher. Here, Lana explained her answer to a problem in which a 3-unit weight at a 3-unit distance had to be balanced by a 4-unit weight on the other side of the beam, "I think 2.25 because, because 3 times 3 is 9, and 2.25 times 4 equals 9." Randy, who had earlier used a ratio rule when the weights were in a 2:1 relationship, could no longer describe how his rule should be applied in this situation. Later, asked by the teacher to explain what Lana meant, Lea said:

> I think she said, if there is 3 weights on, the numbers on 3, and 3, and multiply 3 by 3 and that's 9, and then for the other side, you try to find the number that you multiply by whatever number it's on, and then that's how you find out.

Because students could talk through the problems using Randy's (ratio) rule only when the relationship was 2:1 or 3:1, the teacher provided repeated opportunities for Lana to explain to others who said they did not understand. Thus, while Randy's law was recognized as viable within this class, it was not applicable to all situations. The teacher's instructional move to emphasize "Lana's (product moment) law" rather than "Randy's (ratio) rule" was then based on previous research which indicated that many students find it easier to develop a discursive practice related to the product moment rule rather than the ratio rule (Roth, 1991). During the same lesson, Lana had two more opportunities to explain how she did balance beam problems:

> I find the number that they are both equal like if there's 4 on 3 then that's where you can move, 4 times 3 is 12, so you have to find something that 2 multiplies by to get to 12

> Well, there is another way, is like, well, say 3 times 4 is 12 then, well, you need another 12, and if divide 2 by, divide 12 by 2 which is 6, that's another way to get the number.

However, other students did not consider Lana's new language game very accessible. For example, in one episode during the following lesson, Lea explicitly questioned Lana's account ("What is 8 have to do with it? Because there is no 8 thing on here, because there is 6 weights, not 8?"). Lana provided another description of her method which led to further examples and explanations of the rule. At the end of the second whole-class conversation relating to balancing the lever, the teacher suggested:

> WMR: I want to summarize Lana's law. She says multiply the load by the distance (writes on the overhead) and that has to equal what, Lana?
>
> Lana: That equals the effort times the distance.

The results of the two discussions were posted as "Lana's law." In a similar way, the ratio rule for doing balance beam problems was posted as "Randy's rule."

Further Opportunities

Later, during another lesson on second class levers, the teacher asked students how one could know the force needed to hold up a "wheel barrow" (second class) lever.[4] Shaun referred to the posting of Lana's law, got up and read it to the class. Using the posting as a resource, he paraphrased, "multiply the load by the distance and you get a number, then find the distance for the effort so when you multiply them, you get the same number so, effort times distance, and load times distance." Further applications of the rule where provided during the discussion of "catapult" (third class) levers, where the entire class hypothesized the size of effort given the load and the distances.

Students built levers into their machines. Nana and Ellice built a crane-like structure in which a 100-gram load at the end of a long arm was counterbalanced by a heavy weight (hammer, sand bag). Marilyn and Jane produced a similar design. Four groups (11 students) also employed levers as central parts of their final, integrating project. In these projects, the relationship between the weights and their distances from the fulcrums needed exact timing in order for the devices to work. Thus, the students had ample opportunities to explore levers and their relationships in more detail. We have to be careful, however, and not assume that because students had opportunities for solving mechanical problems in their designs they would develop better language games relating to the product moment rule, that is, "Lana's law." The problems of getting the timing right can be done without invoking the product moment rule. Rather, the situation was quite different so that it was expected that students would use different structuring resources to resolve the contingent problems in the design and construction.

There were further opportunities for talking about various lever problems. During the students’ final project, a "review" of the lever activities allowed students to hypothesize and test, in whole-class situations, further problems; when called upon students described how to derive their answer. Various students used the product-moment rule which was, again, associated with its originator, Lana. In another whole-class conversation about pulleys, the teacher showed how Lana's product moment rule could be applied to pulleys by using a diagram that highlighted the structural similarities between pulleys and levers.

Levels of Appropriation

On the written posttest, three students applied the product moment rule correctly to all three problems, three students correctly to the second class lever problem; three students provided the product as the answer rather than the missing distance information on the effort side (one of these explicitly referred to "Lana's law"); three students incorrectly "timesed" some of the measures (two distances, or a distance and the opposite weight).

During the posttest interviews, students evoked the names of the rules and laws posted, but they had difficulties using the associated language game to describe how to balance the equal arm levers or how to find the effort in a second class lever.

> Well, anyways I, OK, I'll go, I got my answer by timesing 50 by 6 'cause 50's there and 6 is what it's on, o.k., and that gave me 300 grams, same as Celia's. (Krista)
>
> I did weight times the distance, like Lana said on, well while we were doing our lessons, she said that the weight times the distance would be, so I timesed 50 by 6 and got 300 as well. (Celia)
>
> Well, no, that's kind of what, I was going to do, but I guess I kind of, I guess I divided it by the six, but I... 'cause like Lana had hers. (Amy)

The language game can be interpreted as getting halfway there. The three girls appropriated only part of the description provided by those students who intentionally used the language for providing an answer (Lana, Jon, Brenda, Randy, and David).

"Lana's law" as a resource becomes clear from our observations that students indicated a particular problem could be done by applying this law, but could not actually do it. Similarly, during a whole-class discussion on second class levers, Shaun answered the teacher's question about how they could figure out the effort knowing load and load distance and effort distance, by walking to the bulletin board and reading "Lana's law." It was an index to a practice which was easily available; and students knew that it was posted as such. We gathered similar evidence in other situations such as the conceptual difference between pulley configurations. During the introductory discussion, the teacher employed the letters "A" and "B" to distinguish the drawings of two different pulley configurations, one provided a mechanical advantage of MA = 1, the other MA = 2. Students later used the labels "A-pulley" and "B-pulley" as convenient indexes. In several situations, students later used the labels "A-pulleys" and "B-pulleys" to help them whether or not pulley configuration decreased their effort. Here, the students' answers to a problem were mediated by the enunciation of a label rather than by a straightforward description of the system itself. "A-pulley" and "B-pulley," posted copies of transparencies, and the transparencies in the teacher's binder were resources for students' practice to talk about and build pulley configurations. Again, while these resources were rapidly available, the associated (discursive and tool-related) practices were less rapidly appropriated.

Discursive Practice Introduced by the Teacher

In this section, the language game about "mechanical advantage" is used to illustrate students' rapid appropriation of a discursive practice although it was introduced by the teacher. The process of appropriation was roughly divided into four periods. First, the teacher introduced the new language game about "mechanical advantage." Then, students participated in this discursive practice in whole-class settings where the teacher could observe their first attempts. Third, structured small-group activities provided students with situations in which they could try to use the mechanical advantage language game on their own. Finally, the community appropriated the language game about mechanical advantage and populated it with their own intentions.

Introducing the New Language Game

To introduce mechanical advantage, the teacher began the lesson by asking students about the purpose of machines. This question had been previously the topic of an extended class discussion. Several students responded again that the purpose was to make life easier. The teacher than introduced a formal way of assessing how many times the effort becomes easier. This definition was at the same time formal, ratio of load and effort, and an operational definition of how to measure load and effort.

> So if you take the load and divide it by how much effort it takes you, the load that you hang on your machine divided by the effort. Now, if MA is greater than 1, if you take your grams, that you hang on your machine divided by the grams you have to crank or pull, then you get the mechanical advantage, if it is greater than 1, you have a mechanical advantage. If it is less than 1, you have a disadvantage (writes on overhead).

Here, the possibility of associating the formal definition of mechanical advantage with the everyday notions of advantage and disadvantage was provided. The teacher explicitly linked MA < 1 to disadvantage. His next example tied the present discussion to Alain's presentation on the previous day, further encouraging this discursive bridge ("Alain showed us a machine that had 75 grams as a load, and then it took us 100 grams for the effort. Now if you divide 100 into 75, you get?"). After students performed the calculations and provided the numerical answer, the teacher continued:

> It's less. Now let's go back. If it's less than 1, the mechanical advantage, less than (<) this means, less than 1 you have a disadvantage. So this is the same way that we can look at all of your machines, after you presented and to take some engineering criteria to your machine.

The immediately following presentations of student-designed machines provided opportunities for employing this language game and for students to engage in this practice. Subsequent lessons provided further opportunities for using "mechanical advantage" in the context of student- and teacher-designed machines.

First Participation in Practice

The whole-class conversations following students' second design and construction activity provided many opportunities to engage in the practice of measuring mechanical advantage and to refine the associated discursive practices. Episode 2, recorded during David and Shaun's presentation, clearly illustrates this.[5]

Episode 2

		AUDIO	VIDEO
2.1.	Marilyn:	OK, where is your advantage? and=	
2.2.	David:	=Right here, see this, I geared this down, this /is a gear box]	[Points to gear box]
2.3.	Marilyn:	OK, let's measure] it and see what your effort is.	

2.4.	David:	Our effort /we can't, it is not possible.]	
2.5.	Shaun:	There is no effort, all] we have to is let it go.	[Shows how load is released]
2.6.	Marilyn:	Then it's not, there has to be an effort, or else it is not like everybody else's.	

Marilyn's opening comment (line 2.1) illustrates an initial way of talking about mechanical advantage, "Where is your advantage?" However, in response to David's pointing to a part of his machine, she repaired her earlier phrase and suggested a measurement of MA. Her comment in line (2.6) shows that David's and Shaun's way of describing mechanical advantage not only conflicted with her own ways, but with those that she perceived as shared by the community, "it is not like everybody else's" (line 2.6). This critique was further sharpened when other students in the audience refused to accept pointing to the gear box as a description of mechanical advantage.

	AUDIO		**VIDEO**
2.7.	Andre:	What's the mechanical advantage?	
2.8.	David:	Right here.	[points to gear box]
2.9.	Andre:	No, no, measure it.	
:::::::::::::::			
2.10.	Lea:	People asked you why your mechanical advantage was, he said it was this. But in everybody else's machines, the mechanical advantage was a number.	[walks to the front and points to gear box]

Here, Andre followed Marilyn's rephrased line of inquiry; he asked "what is" rather than "where is the mechanical advantage?" (line 2.7). In her rejoinder, Lea made it quite clear that for most in the community, the shared understanding of mechanical advantage required it to be expressed as a number (line 2.10).

In this way, more and more members participated in the new language game about the mechanical advantage of machines. The teacher encouraged students not only to talk about and assess mechanical advantage, but also to describe current problems reducing the mechanical advantage, and to suggest modifications improving it. Sometimes he directed students' attention to specific aspects of the design which brought up the idea of friction which decreased MA. Later, various students began to offer suggestions for how to overcome the friction problem. In one situation, the mechanical advantage was 2. Although this satisfied the criteria for a machine decreasing effort, the teacher asked students how they could improve the design to increase the mechanical advantage. In the subsequent conversation between presenters and the audience, various students suggested:

> Well, if you use, if the car was part of your machine, if you wanted it lighter it would be a better mechanical advantage, if it was like plastic or something light, it's wood so like it takes away some advantage. (Alain)
> When you are pulling the string, and if it was a big machine, and you were pulling it, that takes off some mechanical advantage, and also when you are pulling the string, your little car over there. (Shaun)

> A better pulley, because, like here, Claire had to hold it so the string wouldn't come off, so it something that lifts over it so that the string wouldn't come out. (Krista)

First Attempts during Structured Activities

The small-group activities organized around teacher-designed artifacts and worksheets provided first opportunities for students to deploy new language games on their own. (All previous opportunities were in whole-class discussions and in the teacher's presence.) Here, students could negotiate their differences and develop ways of talking that were shared within the small groups. There were ample opportunities to stabilize this talk.

Episode 3

	AUDIO		**VIDEO**
3.1.	Ellice:	What is the mechanical advantage of your pulley system?	[reads from instructions]
3.2.	Alain:	There isn't one.	
3.3.	Ellice:	There isn't one? I'm gonna say it was a disadvantage.	[begins to write an answer]
3.4.	Alain:	What are you doing? Ellice, no, no, no!	
3.5.	Ellice:	Just say it was none.	
3.6.	Alain:	You have to put like something divided by something.	
3.7.	Ellice:	OK, it was 50 over a 100	
3.8.	Alain:	No, 100, no 100 and (.) 2.	

In this conversation, Alain and Ellice develop a description of two pulley configurations in terms of mechanical advantage. Although Alain began by noting that there was no mechanical advantage (line 3.2), he later changed this description to "2," after having suggested that mechanical advantage involved "something divided by something." In this, he rejected Ellice's formulation "Just say [mechanical advantage] was none" (line 3.5) and supported a mathematical formulation. He inverted Ellice's suggestion (3.7) to arrive at the canonical form of load/effort.[6] This episode also illustrates the presence of the everyday discourse in Ellice's utterances "disadvantage" and "there was none," and the emergence of a new discourse in Alain's "something divided by something." "Something" constituted two yet to be specified variables.

While we observed students develop this new way of talking, we understood that a full appropriation of the new language game in this community was only expressed when students deployed it in the pursuit of their own intentions. Opportunities for observing such a development of the shared language was provided during students' design and construction activities.

Core Participation

Designing. The language game surrounding the mechanical advantage of machines was rapidly appropriated by students. Building on students' definition of a machine, the teacher encouraged students to design their machines in such a way that "it makes it easier for [them] to move the load." Without further emphasis on mechanical advantage, the teacher asked students to begin designing a machine that could move heavy loads over a large distance. The model of the device designed and constructed by the students was to be able to move a load of at least 100 g over a minimum distance of 2 meters. In the course of this activity, we had many opportunities to observe students concern for mechanical advantage, both as a discursive practice (designing machines which decrease the amount of effort, and designing tests) and a tool-related practice (building the machines, and conducting tests).

While we do not have evidence for all groups, we observed many for which the following episode during the planning of the "transporter" was typical.

<u>Episode 4</u>

	AUDIO		**VIDEO**
4.1.	Jon:	Is that your model of your model? Don't Dave. No, but do you know what I'm saying. We could use that old one [from their previous project] and then you could crank it up and then slide down into the truck.	[they turn back around]
4.2.	Dave:	But see that wasn't a mechanical advantage.	[starts erasing his design again]
:::::::::::::			
4.3.	Dave:	Up here could be the warehouse. Hook the weight onto there, it slides down there, hits that and slides into the truck.	
4.4.	Jon:	But it needs to be a mechanical advantage instead of pulling it. We need to get it up there somehow.	

Here, Dave and Jon raised each other's attention to the problem of designing a machine that had a mechanical advantage. Jon proposed to employ a design element used in their previous model (line 4.1). Dave responded by pointing out that their previous tests showed the element not to provide a mechanical advantage (line 4.2). A few moments later, Dave proposed a design for their transporter, but Jon critiqued this design in terms of mechanical advantage. Here, we see one of the many examples where students used the language of mechanical advantage to analyze and improve their design; they used it for their own intentions rather than parroting a teacher statement, or filling in some blank where this would be the required canonical and teacher-appraised answer.

This evidence, however, does not provide the entire picture. We observed repeatedly that students could accurately analyze situations on paper and provide descriptions compatible with canonical discourse; but, had not yet developed an equivalent competence in their tool-related practice that would allow them to actually construct a pulley configuration that would increase the mechanical advantage. However, during the design and construction activities following the introduction of mechanical advantage, we saw most student groups engage in testing their designs.

<u>Testing</u>. There were increasing instances in which students' concern for mechanical advantage was registered. Some approached us to report that their machines provided some specific amount of mechanical advantage; and they provided us with

specific factors that increased the mechanical advantage in their model. For example, Lana and her group had chosen an arborite surface for moving objects because this "increased slippage." We observed that most student groups began to test their designs, typically after they had finished their construction activities. They used the spring scale available on a specified desk as a resource. Over time, many students used Brenda's set of keys which was known to have a mass of 100 grams, as a reference object to be used in measurements of mechanical advantage.

During the construction phase, students maintained their concern for mechanical advantage. Some, like Jon and Dave began their tests even before the entire model was in working condition. Jon called on Dave:

> Dave, what we should do is a 25 gram weight and then just get a piece of string and right now just see if it is a mechanical advantage... I just want to do this to try it. Let's just do this to test it, I just want to test it.

Dave agreed and they prepared a test for the model at the current state of development. As they set up their test, Jon and Dave already identified possible problems with their model in the current state.

Episode 5

	AUDIO		**VIDEO**
5.1.	Jon:	We shouldn't use shoelaces.	
5.2.	Dave:	Well we're just measuring it.	[Dave attaches the wooden block to the shoelace and it stretches down to the ground] [Both try to bring the lower part of shoestring up, and raise the block off the ground]
5.3.	Jon:	°Tie a knot. Yeah. And then like, yeah, whatever°(…) Okay now we need the scale again (…) Move that up.	
5.4.	Dave:	Well there's going to be pulleys.	
5.5.	Jon:	We won't know, but it can't be dragging against the ground.	[Both try to bring block off the ground]
5.6.	Dave:	I know, we're just using it to see.	

They realized that the thickness of the shoelaces (line 5.1), the lack of pulleys as support for the moving lace (line 5.4), and the fact that the load dragged on the ground (line 5.5) would decrease the mechanical advantage. But Dave repeatedly encouraged Jon to view this as a preliminary test (lines 5.2, 5.6).

Their test showed a disadvantage (MA = 0.3), which encouraged Jon and Dave to talk about the weak points in their present model, derived mostly from friction caused by various features in their test. Subsequently, they talked about replacing the currently used popsicle sticks with pulleys so that the central part of their model, a string, moved with less friction; they also discussed replacing the shoelaces with finer string that was to be strung more tightly so that they would reduce friction with the support, and eliminate dragging of the load on the base. Dave and Jon implemented these changes which improved the performance of their machine about 17-fold so that they achieved a mechanical advantage of 5.

Discussion

Our study had two main purposes: (a) to test descriptions about learning in a classroom environment where students pursue open-ended design projects, and (b) to clarify the notion of "ownership" as it pertained to resources and practices in the classroom community. With respect to the first purpose, we were able to confirm previous observations about the transformation of resources and practices available to individual members of a classroom community. When students interacted with others, they continuously adjusted their activities, problem frames, task conditions, preferred materials, and explanations and stories. Such learning from the community at large occurred most frequently where students gathered closely. Information and ideas were also exchanged in whole-class sessions. The appropriation of tool-related practices could be described as trajectories from limited peripheral participation to full participation in the practice. More knowledgeable peers and teachers served as old-timers who facilitated the incorporation of new members to initially small groups of "experts." In this process, newcomers learned by participating with more competent peers and teachers in "authentic" tasks; that is, those required to achieve the students' own goals (design, construction). The trajectory along which newcomers became old-timers involved transformations associated with the embodiment of practices in individuals, and as a consequence, in the practices available to the entire community.

Our second purpose was to clarify the notion of "ownership" and the appropriation of resources and practices by individual members of the classroom community. The data presented here illustrate the students' contributions to the building of a community in which an appropriate (from a scientific perspective) language game about mechanical advantage came to be shared by a large majority of members. Although the notion of mechanical advantage was introduced by the teacher, the use of advantage and disadvantage is current in everyday discourse. Advantages and disadvantages were common aspects of students' language games in and out of schools prior to being made the focus in this science class. The shift in language from "advantage" to "mechanical advantage" is small; the associated mathematical discourse requires the comparison between effort and a reference load. Even if students did not calculate mechanical advantage at first, they could easily assess whether their machine provided an "advantage" or a "disadvantage." With repeated use during whole class conversations over and about students' models and the teacher-designed pulley configurations and transparencies, students quickly appropriated the new language game. That is, in the case of mechanical advantage, the classroom community had the opportunity to develop a "special network of recurrent conversation" (Winograd & Flores, 1987, p. 158). Across situations—small-group and whole-class conversations, design activities, and structured investigations—mechanical advantage became a central aspect of the language game about simple machines.

On the other hand, the situations in which "Lana's law," "Randy's rule," or "Alain's rule" were deployed as formal, appropriate practices that did the task at hand were more limited. When levers were involved in the design of a machine, other concerns predominated in the language game which did not require any of the formal, mathematics-based rules as discursive resource. Thus, there were few opportunities for an emerging network of recurrent conversation equivalent to the mechanical advantage case. Lana's law (and the others for that matter) was not usually evoked as a resource in talking about students' designs. While most students had developed a qualitative discourse about levers (shown in the posttest conversations), the quantitative discourse never became part of other activities. It was limited to the few whole-class and small-group activities especially designed for lever talk. In this case, in spite of the fact that a student was the originator of a description, and in spite of repeated opportunities to engage in this discursive practice, it was not appropriated widely in the classroom community. Ownership in its narrow sense, as a description of who generated a language game does not constitute an appropriate explanation. It can be argued that most of the students have not had the opportunity or interest to appropriate the language game, to make it their own in Bakhtin's (19981) sense of populating it with their own intentions. Thus, "Lana's law" existed as a resource; when asked, students could refer to its posted instantiation. Some students knew that it described the way of finding the required information on lever problems, but were not competent in deploying this practice. However, the discourse surrounding "Lana's law" did not become as much a part of the daily classroom practice as that surrounding "mechanical advantage."

We can now test whether our new understandings are consistent with the data constructed as part of earlier research projects. Such a "transferability" test is possible because of the extensive nature of these data sources; rather than collecting new data sources these existing databases serve as test cases for our new constructions. Here, we applied our new understandings to two previous instances. The first was an investigation of students' discursive practices as they interacted over and about a computer-based Newtonian microworld (Roth, 1995a, b); the other test was in the study of knowledge-building communities in a Grade 4/5 unit on civil engineering where we had established our first understandings of the processes by which resources and practices became available to the classroom community at large (Roth, in press-b, c).

We now understand the enormous time and effort required to bring about a community of "triangle" practice: (a) students had no prior language game for designing with "triangles" and (b) lacked opportunities to build and engage in a shared discourse. First, in contrast to the closeness of the talk about advantage and the more technical mechanical advantage, the Grade 4/5 students did not bring an equivalent language game about bracing using triangular configurations to class. Second, there were few public discussions in which structures were tested and analyzed in terms of weak points. In contrast, if relevant issues were not raised by students, the teacher in the present study encouraged them to discuss and test mechanical advantage for every project presented. More so, the discussion did not end with measuring mechanical advantage, but the teacher encouraged students to talk about features of the presented models which decreased the mechanical advantage and to suggest changes that would increase it. Thus, the entire community engaged in discursive and tool-related practices associated with mechanical advantage. The initial gap between the teacher's and students' pre-unit discourses was narrow; thus, (mechanical) advantage (and its correlate of disadvantage when MA < 1) provided an opportunity for a common discourse to emerge. A corresponding context in which a common language game was to be developed did not exist in the Grade 4/5 case of triangular bracing. A similar observation was made in a second study in an entirely different school context, region of the country, age level, and course (Roth, 1995a, b). In a Grade 11 physics course, "This arrow is forcing it that way" was a crucial step in forming a new language game about the effect of force and velocity on the motion of a particle. The students' everyday talk about "forcing" became a stepping stone, a pivotal move in the shift that allowed students a convergence of their language game with that of canonical science.

Closeness of language games and critical situations for developing discourses shared by teachers and students seem to be central. The notion of ownership, which we thought was tied to bringing about a practice turned out not to be a suitable way of describing the process of community formation. However, our notion of ownership may have been too simplistic. One can claim that this notion still operates, but now with respect to the appropriation of new discourses. Ownership may reside in students' ability to make a language game their own, whether or not they invented it, that is, in the ability to populate the language game with their own intentions.

From a methodological perspective, this study also explored new ground. Replication and confirmation, while important aspects of classical experimental research, appear to be of little interest to naturalistic inquiry (Lincoln & Guba, 1985). Nevertheless, we felt that a "confirmatory" ethnography would assist us in teasing out which of our working hypotheses could be transported into a new context. If qualitative education research is to be helpful to the community at large, one has to be able to show how and in which way understandings of one context are applicable to another. Lincoln and Guba (1985) suggest that thick descriptions are fundamental prerequisites for such tests of transferability. In our situation, with thick descriptions for several contexts and part of the research team participating in all studies[7], we were also able to test new hypotheses in a "backwards" manner. Thus, we checked working hypotheses generated here against previously established, existing databases. We feel that in this way, we are able to derive valuable understandings with the potential to be transferable to other educational settings.

Implications

In the past, researchers and teachers frequently assumed that when children were allowed to invent and use their own scientific and mathematical language games, they would automatically take ownership (e.g., Cobb et al., 1991; Lampert, 1986; Roth, in press-b). This study allowed us to separate "ownership" and "inventing" of a language game. We now look not simply at whether activities allow students to invent and deploy their language games, but whether activity structure and artifacts in the students' and teachers' experience allow them to build a common language game. Curriculum designers (including teachers) face the same problems that have been described for the designers of computer systems. One of the hardest challenges is to design the participants' environment in such a way that they can create and deploy language games that make sense to all (Ehn & Kyng, 1991). Professional curriculum designers and teachers are the play-makers who set the stage for participation in language games by finding and supporting ways in which students and teachers can, as a collective, develop new ways of talking science sensible to students and legitimate for the teacher. The starting point has to be a language game sensible to both; from this starting point, new and more viable language games can be constructed by the collectivity, students and teachers alike. Ehn and Kyng suggest that in this effort, it is not important if the artifacts which serve as conversational topics mirror "real things," but whether they encourage interaction and reflection. These new language games enable students to see the world in new ways; for language games and the world mutually constitute each other. And because children coparticipate in establishing and maintaining these new forms of talking, they are, as Bakhtin (1981) would say, populating the language games with their own intentions.

Artifacts and activity structures have to be designed to allow participation of all students and teachers; and they must enable and empower learners to change the intensity and depth of their participation with their changing competence in the current language games. Brown and Duguid (1992) suggest that learning is undermined when artifacts and instruction are used to distinguish learners from experts or when they are used to isolate the language games of newcomers and old-timers. While learning still goes on in such environments, the language games are not authentic, but lead to "interstitial communities" (p. 169). Applied to science teaching, students would learn some hybrid talk, specific to legitimated classroom science, but not one that they ever legitimately appropriate or populate with their own intentions.

We propose that curriculum design efforts should develop activity structures and artifacts that allow students and teachers to create and maintain language games. Research associated with such efforts can subsequently study the affordances of activity structures and artifacts to the emergence and maintenance of language games. Some of the questions for research to answer are, "What are the trajectories of evolving language games?," "What are the critical notions that allow the development from everyday to scientific forms of talk?," and "What are critical events in the emergence of new forms of science talk?"

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NOTES

[1] We use the notion of "action" as it is employed in the literature on situated cognition (e.g., Lave, 1988) and in pragmatist philosophy (e.g., Rorty, 1989). Accordingly, actions are the things people do to achieve their intended goals; these actions can be verbal, physical (pointing, gesturing, doing), or instrumental (using tools).

[2] We use "ideas" in the sense of "having an idea of something." In this sense, "idea" does not necessitate appropriate use of a language game or a tool-related practice, but is a resource for future action. In a detailed case study (Roth, in press-c), we showed how Andy attempted to copy the idea of a "spaghetti stretch strengthing technique." It was only through a protracted approximation of his actions to image of the thing that Andy came to know, as a tool-related practice, the "spaghetti stretch strengthing technique."

[3] The following transcription conventions are used:

"(…;…)" to indicate pauses. Each triplet corresponds to one second.

"(.)" to indicate noticeable pauses less than 0.5 s.

"/I agree]" followed in the next line by "this is]" to indicate the overlap of "I agree" and "this is" by two consecutive speakers.

"°Tie a knot°" to indicate low volume utterances.

"=" to indicate latching, i.e., the fact that the following utterance was spoken without the pause normal for turn-taking.

"ah:::n" to indicate drawn out pronunciation of the previous phoneme.

"We're" to indicate emphasis on “we”.

"(??)" to indicate approximately two words could not be deciphered.

"::::" to indicate lines omitted from the original transcript.

[4] Using familiar names and structural resemblances with familiar objects was part of the attempt to take students’ own pre-unit language games as the starting point and not force changes faster than the community could handle.

[5] To better understand this episode, we offer the following crucial background information. David and Shaun were two rather dominating Grade 7 students who were often very acrimonious in their critique of others' work. David usually displayed great discursive competence relating to all matters of simple machines and tool-related practices. Shaun was less competent, but a very forceful debater. Andre, Marilyn, and Lea ended in the two bottom quartiles on our competence measures.

[6] In this class, formulas were not practiced nor requierd of students. A detailed analysis the full extent of which goes beyond this paper shows that children's analysis of

mechanical advantage was more a comparison of load and effort rather than algorithm-based, that is, a definition-based calculation of the fraction load/effort. Ellice's "it was 50 over a 100" has to be read as the convention to write load above effort.

[7] The fact that some of us participated in the earlier ethnographies and that we had access to the entire data sources gives us an advantage over other authors who try to test the transferability of understandings solely on the basis of published reports (e.g., Schauble, Glaser, Duschl, Schulze, & John, 1995).