Children's Understandings of Machines: Meanings, Conceptual Organization, and Discourse

An updated version of:

A grade 5 unit on machines: Children’s understandings and discourse

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Children in North America, as well as in many countries around the world, come into contact with technological devices of many kinds. The notion of "machine" extends from a crow bar to a computer. However, the dominant "machines" in a child's environment are of the "high tech" variety. The notion of traditional "simple machines" is not an obvious component of children's experiences (although there are many examples of these simple machines in children's homes). The purpose of the present article is to examine children's ideas of machines before and after an instructional unit, in which the primary focus of activities is on simple machines. How do the instructional activities impact children's understandings and the meanings they hold about machines? What kinds of changes take place in conceptual structure? How are their understandings used in the context of discussing machines and of working through problems involving machines?

Background

In a review of the literature, only one study of children's understandings of "machines" was found. A study by Brandeis (1992, April) explored the ideas of children in kindergarten and grades 2, 4, and 5. He categorized a number of criteria children held of "machineness." These criteria included (a) control, which included switches; (b) power source, including electricity and gasoline; (c) autonomy, which focused on how machines should do a significant amount of the work; (d) motors; (e) functionality, which focused on machines as being useful; and (f) complexity, which referred to machines having a variety of internal parts, such as gears. More difficult mechanisms for the children to explain focused on remote control and washing machines, as one particular example of a machine that performs a number of actions.

In a study of third, fourth, and fifth grade students' understandings of motion, Ramadas (1989) found that children view motion or movement as planned, deliberate, and controlled. In addition, the meanings that the children held included (a) extensive and elaborate memories from personal experiences and (b) personal feelings about movement and motion. Such an extended sense of meaning relates to the notion of contexts of meaning discussed in several earlier articles (Bloom, 1990; 1992a; 1992b). This notion of contexts of meaning can be thought of as a dynamic association of multiple perspectives or multiple understandings. Such multiple understandings are embedded in and influenced by: (a) semantic knowledge; (b) personal experiences; (c) metaphors and analogies; (d) interpretive frameworks (such as, anthropomorphism); (e) emotions-values-aesthetics (EVAs); and (f) imagery, narratives, and elaboration. The contention is that children construct meaning with more than semantic knowledge alone. Each of these aspects of contexts of meaning can not only contribute to what is included in children's meanings and understandings, but can also influence the processes by which such meanings and understandings are constructed (Bloom, 1992b)

Although these past studies of the understandings and meanings held by children are important in extending our knowledge of children's cognition, we also need to consider the significant aspects of conceptual structure and how conceptions change. Keil (1989) discusses several important aspects of conceptual structure. In the present article, two of these will be considered in analyzing the data: (a) defining features (or essential attributes) and (b) characteristic features (or inessential attributes). In addition to these two kinds of features, the analysis of children's ideas in the present study considers six other aspects: (a) prototypes, which the children consider to be their most typical example of machines; (b) exemplars, which are the examples of machines provided by the children; (c) relations, which are statements that connect features, exemplars, or other conceptual aspects with each other or to different contexts; (d) emotions-values-aesthetics, which are common components of the meanings children hold; (e) metaphors and analogies; and (f) stories or fantasy.

However, looking at children's individual conceptions does not go far enough in helping us understand the dynamics of learning and making sense of phenomena in the classroom. Rogoff (1990) has pointed out the importance of looking at children's learning and development in the context of social interactions with adults and peers. Not only is the notion of having students talk among themselves as they socially construct knowledge and meaning important, but also the notion apprenticeship with the teacher is viewed as an essential component for helping children construct more scientifically appropriate understandings and develop more scientifically coherent ways of expressing themselves (Gee, 1994, April; Warren, Rosebery, & Conant, in press).

In order to develop a better understanding of how children think about and use their ideas about specific phenomena, in this case "machines", we need to look at the dialogue or discourse that occur between children in a group and between children and adults. From the work of Gee (1994, April); Deanna Kuhn (1989); Morrison, Newman, Crowder, and Théberge (1993, April); and Warren, Rosebery, and Conant (in press), the data from the present study will also be analyzed in terms of three general types of discourse: (a) story-telling, (b) "schooled" talking (school knowledge or "correct answers"), and (c) sense-making. Story-telling is a more spontaneous way of talking about objects or events based primarily in personal experiences or imagination. Schooled talking reflects an "authority-based way of knowing" (Morrison, et al., 1993, April, p. 3). Sense-making conversations can be characterized as science talk, in which students are trying to coordinate their explanations or theories with appropriate supporting evidence. However, Gee has pointed out that not all sense-making conversations are indications of authentic "science talk". Students often rely on their everyday language when making sense of particular problems or phenomena. Such everyday discourses are distinguished by their use of "patterns and associations, repetitions and parallelism, what might loosely be called 'poetic' devices, to construct (or, as here, to co-construct) a senseful (sense making) design" (Gee, 1994, April, p. 5). Such everyday sense-making tends to obliterate the underlying concepts and meaning, to "obscure the details of causal, or other systematic, relationships among things in favor of rather general and vague relations" (Gee, p. 6). In scientific discourse, we would expect to see more of an effort to pin down the mechanisms, concepts, and meanings of the phenomena being investigated.

In addition, Cortazzi (1994), in considering schema theory (based on evidence from Bower, 1976), contends that stories with more well defined goal structures are more coherent and comprehensible. So, we need not only to consider how students attempt to identify and discuss scientific mechanisms, concepts, and meanings, but also to consider how students articulate their ideas and how coherent and cohesive these expressions are.

Method

The present study was conducted over a period eleven months, including pre- and post-data collection meetings with the teachers involved. Although the research project involved four teachers and their classes, this article will focus almost entirely on one teacher, Mrs. Landry (pseudonym), and her class or 28 students (15 girls and 13 boys). The school was brand new and situated in a suburban neighborhood of a small city in eastern Ontario and was in its first year of existence. The focus of the study revolved around a machines instructional unit implemented in mid-January and continued through mid-April.

Data Collection

The data focused upon in the present article were collected in a variety ways, including pre- and post-unit meetings with the teacher; pre- and post-unit interviews, context mapping tasks, and written definitions completed by the children; and participant observation prior to and during the unit of instruction, aided by field notes, audio recordings, and video recordings. The pre-unit tasks and interviews were completed over a period from mid-October to mid-December and the post-unit data were collected from mid-April to early June.

The pre- and post-unit semi-structured interviews asked similar questions, for the most part. The significant questions in both interviews centered around (a) children's experiences with machines in their homes; (b) how they would define a machine; (c) a hand-drill they could manipulate and use, and how they could explain how it worked and whether they considered it to be a machine; and (d) explaining what they had put down on their context maps and written definitions. The written definition task asked the students to write a definition of machines or what makes a machine a machine (the term "define" or "definition" was not clearly understood by a number of the students). In the context mapping tasks, students were asked to write the word, "machines", in the center of a large sheet of paper, then write down everything they could think of that related to machines around the word. When they had finished listing their ideas, they were asked to draw lines between the words that were related or connected in some way. Along this link or connecting line they were asked to write a word or phrase that described why they connected those particular words or how they were related. Prior to doing the machines context maps, an example context mapping task using the word, "school", was completed as a class on a large sheet of paper posted on the wall. (For further information on context mapping, see Bloom [in press]).

Of the 28 students in the class, 25 complete sets of data were obtained. One student was absent for an extended period of time in the fall and the other two students did not complete specific tasks. Pseudonyms have been assigned to all students. Further details on students will be supplied in the Results section.

Results

The following discussion of the results will initially develop an overview of the instructional context (classroom setting, instructional context, and teacher reflections). After this introduction, a broad view of the students' understandings and contexts of meaning will be explored, followed by a more detailed examination of conceptual organization, continuity, and change. Finally, the dynamics of student scientific discourse will be explored.

Classroom Setting

Although the school was new, it was already overcrowded. The classroom in which the present study was conducted was not originally intended to be a regular classroom. The only windows opened to two interior hallways. The classroom was smaller than any of the others in the building. Because of the tight quarters, the teacher would often send groups of children to the Resource Center, main entrance hall, and other hallways in order to work on various activities.

The class consisted of 15 girls and 13 boys, most of whom were Caucasian with one African-Canadian child, one child from an eastern European country, and two children of east Indian descent. According to their teacher, the ability levels ranged from gifted to low academic ability. In addition, at least three children may have had some degree of learning disability. In general, the class was well behaved and would engage in classroom activities with varying degrees of enthusiasm.

Instructional Context

The unit of instruction for this study was decided upon by the four teachers in the junior division (grades 4 - 6) in the late spring prior to the year in which the present study took place. The teachers decided to focus on simple machines in conjunction with a history unit on Medieval times. They divided up the planning tasks with each teacher developing a set of activities around a particular simple machine. These activities and necessary materials were put into large plastic bins. The bins were in essence portable learning centers. All of the instructions for activities and questions for students to answer were included in each tub. Although in our initial discussions about the research project we discussed approaches to engaging children in more authentic inquiry with more open-ended problems, the teachers opted for the more structured activities. We also discussed the role of the teacher as a guide in the inquiry process and how children should be encouraged to develop their own explanations, and then to engage in testing their ideas and/or in negotiating acceptable explanations with other students in their group and with the class as a whole. This discussion revealed Bloom's Taxonomy to be one part of the underlying theoretical framework driving instructional decisions:

JB **What else would we mean by inquiry?**
T2 What sorts of things.

JB How do you envision, how do you see inquiry?

Mrs. L Question. Finding it out. Discovery.

T2 Curiosity.

Mrs. L Problems.

T3 Being curious.

T2 Trying to figure out what something's for or (???)

T4 Evolving.

JB Coming up with questions is important. How are the kids with coming up with questions that, well there are different kinds of questions, I mean there are questions that can be answered by doing an experiment or something like that.

Mrs. L Depends on the situation.

JB How do we develop that skill more?

Mrs. L I think the first step is to get them to learn how to answer them.

JB Do you have a story about that?

Mrs. L Well no. I know that when I taught intermediate grades it was a lot easier to, and even they found that a difficult task, try to get them, for example, to use Bloom's Taxonomy to answer different questions. They had difficulty with that. And they used their traditional how, what, when, where, why and that's it. Go beyond that even their expectation of an answer would vary.

In addition, Mrs. Landry frequently referred to "levels" of thinking, application of knowledge, and "evaluation", as in the following post-unit meeting excerpt:

> So I think basically, if I were to do that section again, and I know that if I am doing it differently, um, I would try to get them to use the different levels of thinking.... where they're actually able to apply and able to take it apart and then do something with it and then evaluate....

The unit on machines began in mid-January and extended into April. Although the schedule varied from week to week, four days a week with a half hour to an hour, and sometimes more, per day were devoted to the machines unit. The topics covered in the unit included: "Springs and Stretchy Things", "Inclined Planes", "Gears", "Sticking and Slipping" (Friction), "Pulleys", "Wheels and Axles", and "Levers". (See Appendix A for a list of terms and objects presented within each of the sets of activities).

Teacher's Reflections

The atmosphere in the class was friendly and respectful. Although some groups of children would actively or passively exclude or tease other children, the teacher would frequently use such occurrences to work on building a more cohesive classroom atmosphere. The teacher respected and trusted the children, as demonstrated in her allowing children to express initiative and to take on responsibilities in running the class.

All of the children responded well to the teacher. From conversations with many of the children, they all seemed to like the teacher, Mrs. Landry (pseudonym). From my perspective, Mrs. Landry was gentle, yet firm, with her students. She was quite insightful about the specific needs of each child, and would structure pairings of children, instructional activities, and a variety of other management approaches to meet these needs.

Mrs. Landry expressed her goals in terms of knowledge acquisition (factual content), knowledge application, and the development of argument. In the following excerpts from a post-unit meeting, Mrs. Landry reflects on student performance in light of her emphases on knowledge acquisition as evident in the passages that focus on "pick-up..." and "walk away with information"; on knowledge application as evident in the passages that focus on "follow-up route" and "application of the theory"; and on development of argument as evident in the passages that focus on "couldn't put it into words", "convince me", "prove", and "doing debates":

> They had no idea. They did not pick up the information that we wanted. Yet, they did the entertainment and the activities and they had fun with it. But, they did not walk away with the information. And I think in that way, there had to be more of a follow-up *route* particularly, like the pulleys and, and the inclined plane particularly. Um. When I spoke to students about it, they really didn't have, they couldn't put it into words what they had learned or the reasoning behind it.... The application of the theory I think would have been

> far better. Some parts of the unit though, I found allowed them to take the information and apply it.... I think there had to be more initial involvement. And then... prove to the class that it's a machine... convince me that this is a machine.... Actually, we had them doing debates at the end, the end of May, June. They loved it. But, they would go and they would argue various points, as well. And, they had to really come up with support and they did a good job. I also made them try to listen to the other person's arguments before they had to sort of summarize what the other person said. And then respond to it immediately which, some did a lot better than others.

In the above excerpt, Mrs. Landry's emphasis on having students "convince" the teacher and the class of particular claims was observed throughout the unit. The first time I saw this occur was in early October within an inventions unit prior to the beginning of the machines unit. Mrs. Landry was questioning one group's idea for an "elastic message carrier". Her questioning was quite critical. She kept trying to get the children to explain and think about how their invention would work. The group of four girls initially provided a rather vague explanation followed by assurances that their elastic message carrier would "work". At this point, Mrs. Landry said, "Okay, but you'll have to convince me." The group immediately responded with another explanation, which Mrs. Landry still thought was unsatisfactory. She told the group to take ten minutes and work on a better explanation, and then to present their explanation to the class.

Another point evident from the above excerpt is how the children seemed to be much more interested in the process than in the content. At another point in the post-unit meeting, Mrs. Landry described, "I found that some of the instructions for the kids... it was all a *game* to them. But, then when you asked them what they learned from it, they couldn't tell you." This pattern is also evident in excerpts from post-unit interviews with some of the children (the researcher's speech is in boldface):

> Interview with Andrea:
>
> **... if you had your way at the school, what would you do?**

Make everything *fun*, a *game*....

Uh huh. Which ones did you like the least?

The wheels.

The wheels (laughs). OK. You didn't have to think about that. Why didn't you like that one?

I don't know. It just had <u>too much work</u>. (Both laugh). <u>Too much thinking</u>. I like experiments more. I don't like doing the observations and all that.

<u>Interview with Betty:</u>

Okay. Which was your favorite, which did you like the best?

... The pulleys.

The pulleys? Why did you like them?

'Cause there's <u>fun</u> activities in that.

What makes it fun?

Instead of writing all the time you get to do things...

<u>Interview with Jane:</u>

You liked wheels? Why?

There was more like <u>fun</u> stuff, <u>less written work</u>.

With the previous scenario and data in mind, we will now look at data collected on children's understandings of machines from the more general perspective of contexts of meaning, then from the perspective of conceptual organization, and finally from the more interactive perspective of student discourse.

Scope of Contexts of Meaning and General Understandings

In general, all of the students viewed machines as being electrical or operated by gasoline. If they did not mention "electricity" in their context maps, they provided examples of electrical components (such as wires and batteries) and machines operated by electricity. In the case of gasoline, they provided examples of vehicles fueled by gasoline. In addition, many children (35% before the unit and 26% after) considered "metal" to be a characteristic property of machines.

Table 1 presents an overview of the categories of responses from the context maps. Table 2 shows the most common (19% or above) items appearing within the categories of responses (Appendix B provides a list, organized in order of frequency of occurrence, of all responses in pre- and post-unit context maps). As apparent in the Tables 1 and 2, the predominant items on context maps were examples of machines, and, of those examples, most were electrical or gasoline operated vehicles. One student listed human beings ("us") as an example in the pre-unit context maps. Although biological organisms did not appear in the post-unit maps, three students listed these in their definitions of machines or in their post-unit interviews. Even though biological organisms were mentioned as examples of machines by some children, the same children still mentioned viewed most machines as being electrically or gasoline operated.

Other aspects of machines that were commonly expressed included the notion of control (as Brandeis [1992, April] and Ramadas, [1989, January] have described), such as in "remote control" cars and TVs. The notion of control was sometimes referred to in terms of people working with machines or using them in some fashion. However, some children saw machines as independent of human interaction. The notion of robots occurred in six children's context maps both before and after instruction. "Self working" also appeared on one child's context map. In the pre-unit interviews and definitions, seven children talked about machines that would do chores for you, such as in the following examples:

JB **What robot are you thinking of ?**
Evelyn Just sort of like a... maybe... sort of like a robot that does chores and things like that.

JB **How does it make you feel when you think of machines?**
Ivan Great, because they're like robots and they move around in your house and do all your chores and stuff. But they cost a lot of money.

JB **Do you have anything to add to that definition?....**
Ken It can move. It can go around the house. It can do chores for you.

Kate Run a chore that you can't do like if you broke your leg the machine would do chores, that's what I think a machine is.

Another example from the pre-unit definition of Amanda describes a different perspective of control : "some machines are controled (sic) by wires so if it's full of wires it's a machine." Not only is the control removed from humans and placed with a component of machines, but it is Amanda's defining feature of machines (this notion of defining features will be discussed in detail in the next section).

[Insert TABLE 1 About Here]

The function of machines was most commonly referred to as "helping" (see Table 2). Most of the more specific functions also had to do with helping, such as, cutting, carry stuff, makes food, cleans, and so forth. Other relatively common functions or actions include flying, moves, playing games, and works or working.

Other physical characteristics of machines included size and color. "Big" (seven children before and six after the unit), "huge" (one after), "very large" (one after), "giant" (one before), "tall" (four before), and "humungis" (one before) were mentioned in the context maps. One child said they were big or small and four children before the unit and three after the unit said they were small. A variety of colors were mentioned by six children in the context maps before instruction, but only one child mentioned color after instruction. The output of machines included most commonly noise (five children after instruction), smoke (two before and four after), and pollution (three after). Other output included beeping, flashing, machine talk, and steam.

[Insert TABLE 2 About Here]

In addition to the components listed in Table 2, some examples of components occurring among more than one student include: buttons (five children before instruction and six after), motors (four before, three after), plugs (three after, three after), cords (two before, one after), bolts (one before, four after), engines (three before), computer chips (two before), gears (three after), springs (three after), and axles (two after). A few students added elements from the machines unit activities, such as gears, springs, and axles, however most maintained a fairly consistent list of items.

Several items on the context maps were difficult to categorize because of multiple meanings. The item "lights" is one such example. From the interview data and informal discussions with the children, some thought of lights as a machine, while others referred to lights as components of machines. In the following examples, Ken (post-unit interview) explains how "lighting system" is a machine and Joe (post-unit interview) views a "lamp" as a machine, while Andrea (pre-unit interview) sees "lights" as components of machines and possibly machines.

JB **What machines can you use?**
Ken Uh, I use microwave, toaster, um, lighting system....
JB **Lighting system? How's that a machine?...**
Ken Well, there's a whole bunch of electronics going through the walls, like wires and stuff going through the wall, and there's lights, and it turns them on and off when you want...

Joe And... another machine that we use everyday... is the oven and... oh yeah, and one that we use the most is a lamp.

Andrea Lights sometimes flash on the machines,
JB **Okay, are lights machines?**
Andrea Um ... I don't know, maybe, maybe not.

The data discussed to this point have been semantic in nature. The children's ideas evident in the data are related in some fashion to the conceptual understanding of machines (a more thorough analysis of the conceptual structure of the children's ideas will be discussed in the next section). However, a significant aspect of their conceptual understandings has to do with more personal and idiosyncratic aspects of meaning. The children's personal experiences with machines have not only contributed to their semantic knowledge, but have also lead to the development of interpretive frameworks (notably anthropomorphism) and emotions-values-aesthetics perspectives.

All of the identified evidence of anthropomorphism is connected to the notion of robots. The following data from the context maps are indications of such an interpretive framework: brains, can have fun, cares, doesn't lie, eyes, arms, legs, listening, obeys you, polite, protective, read stories, remember stuff, thoughtful, and works until it wants to. Only "brains" was mentioned by two students, the rest were single occurrences. In addition, arms and legs only occurred in the post-unit context maps, and one mention of "brains" and "obeys" were repeated in the post-unit maps. The definitions and interviews provide a richer view of the students' anthropomorphic frameworks, as evident in the following examples.

> **Evelyn's Pre-Unit Definition:**
> It has to obay (sic) you at all times. Careful and very caring, plus loveing (sic) and thoughtful. Friendly and kind and very special.
>
> **Kate's Pre-Unit Definition:**
> A machine is made with gears and opening body parts like the stomach is an opening door, no heart in a machine arms and legs much like a human and playful and will want to do anything you want to do or walk the dog or clean up after the cat or any chore that you can't do like if you broke your leg the machine would do your chores for you that's what I think a machine is. And I wouldn't like to have one as a parent. Because it would have no heart and wouldn't really care about you because the machine would have no heart that's why I wouldn't want to have a machine for a parent.
>
> **Marsha's Post-Unit Definition:**
> A machine is something that would help you (if it was friendly).... maybe a machine could turn out to be a house kepper (sic) and help my mom. Or a trouble maker and smash everything thats (sic) what I think a machine is.
>
> **Joyce's Pre-Unit Interview:**

Like if they're ... if they're under a spell or something like do things for bad people, like steal and stuff.

Ken's Pre-Unit Interview:

Ken They could .. fight for your country in war ... they could protect you, they can save you. I don't know ... they can cook for you, they can maid service (sic)...

JB These are like robots you're talking about? What about other kinds of machines?

Ken They can cook for you, they can microwave, you can watch them, you can use them for cleaning ... play with them, microwave them, listen to them, say things about them, they'll talk back to you...

Anthropomorphism for some children exerts a powerful influence on their understandings. Machines become more than an object to be manipulated or controlled. Although the anthropomorphic examples are embedded in an imaginative image of machines, the significant aspect of these examples is the notion of personal relationship evident in each of the children's descriptions. In the extreme case of Kate's definition, the anthropomorphic "story" becomes her defining feature of machines.

The notion of personal relationships with machines is extended through the children's emotional reactions, their perceived values (or lack of values), and their aesthetic (both positive and negative) reactions towards machines. Such emotions-values-aesthetics are even more common. Out of 28 children, all but six presented explicit evidence of EVAs in either or both pre- and post-unit context maps. One child, Joyce, listed four EVA items in the pre-unit map and 17 in the post-unit map. Examples of some of the items listed by more than one child in either the pre- or post-unit context maps and which occurred among the children's pre- and post-unit maps include (numbers in parentheses refer to the number of children including the term in the pre- and post-unit context maps): smart (6, 1), fun (5, 4), useful (4, 2), nice (3, 2), ugly (3, 2), dumb (2, 1), helpful (1, 5), noisy (1, 3), and stupid (1, 2). However, in order to get a sense of the extent personal relationship, we need to look at some examples from the written definitions and interviews:

Jane

Pre- Unit Interview (the same reaction of "ugly" occurred in the post-unit interview, as well):

When you think of a machine, what's the first thing you think of?
Ugly.
What are you thinking of?
What do you mean?
What kind of machine?
Well, its ... ... well, I only make machines, I don't know a lot about them so ... well, we have ...I don't like ... VCR's are so ugly.
You watch them all the time?
Yeah.
What makes a machine ugly? What is it about a machine that's ugly.
It has too many buttons.

Pre-Unit Definition	Post-Unit Definition
A mishin [machine] is big and can make stuf (sic). It is made ou [out] of stell [steel] or plasek [plastic]. You do a lot of things with a mishen (sic). You can drost [draw] stuf (sic) on it, stik (sic) stof (sic) on it you could dry out hare (sic) with it. A mishen (sic) is humunis (sic) gigantik (sic) but they are stuped (sic).	A machine is metel (sic) and manmade. They dont (sic) have to be metel (sic) they can be plastic or mabey (sic) glass. Michines (sic) help you but they look junky!

Joyce

Pre-Unit Definition	Post-Unit Definition
I think a machine is very ugly but it helps out sonetimes (sic) and sonetimes (sic) machines can be bad. A machine makes a machine good because it works most of the time and you do not pull it arond (sic) you jest (sic) tell it what to do or puse (sic) a button and it does it for you.	I think machens (sic) cost to (sic) much money like washers and direrers (sic), microwaves, stoves, clooks, radios, T.V.'s, V.C.R.'s, and so on, ect (sic).... I think machens (sic) are hard to make and I think it takes hard work to make a machen (sic) a machen (sic). Because you have to built (sic) it, buy all the wiers (sic) and ectronecs (sic) and to give it testing you have to pay for the elictrisaty (sic) unless it goes on bottons (sic) you have to pay for it so somebody's got to do for us (sic) without clooks (sic) we'd always be late for school (like we care any way).

Post-Unit Interview:

... so ... could you give a definition of a machine? How would define a machine?
Uh, well... I think machines, uh, they take time to let (and???)... sometimes, when you're making them, basically you have to patient with them, because they're not always gonna work out.
Mm hmh.
And I think machines are useful in some ways, but other ways they're just... they just take up space.

Joe

Post-Unit Interview:

...What's your favorite machine?
I think my favorite machine is... is a... a boat.
Boat? Yeah, why do you like that?

> Well... you can travel on the water. And... you can see all around you and, um... well, um, they're pretty neat.
>
> **Yeah. What kind of boats do you get on?**
>
> Um.. Some ferries and... I've been on canoes. I've been on... those, uh, cruise ships, 'a thousand islander.'
>
> **OK.**
>
> Um... oh yeah, a power boat.
>
> **Uh huh. Which is your favorite boat?**
>
> Uh ... I think the big cruise boats.

Children's emotions-values-aesthetics are embedded in their personal experiences with machines. Their EVAs are indicative of their relationships with the objects they consider to be machines in their environment. The stories of their relationships with machines show a range of reactions. Some children see them as ugly and frustrating, others see them as "neat" and useful, while others see both the positive and negative aspects of machines. Several children see machines as dirty and as sources of pollution. Others see them as sources of entertainment and as ways of making chores and other tasks easier. Fundamentally, however, EVAs exert a powerful influence upon the meaning children construct around the conception of machines. Such an influence is powerful because of the strong personal connection that is created between the children's idiosyncratic and socially-shared ideas and their own personal sense of identity. The students' reactions, such as emotions, values, and aesthetics, are personal statements of their views, which can be associated with their own sense of identity.

Conceptual Organization, Continuity, and Change

In this section, we will look in more detail at the conceptual understandings of the children and how they change, if they do at all, after instruction. The theoretical framework guiding this examination is adapted from Keil's (1989) delineation of conceptual structure. For the purposes of this article will consider the following aspects of the children's expressed ideas: (a) defining features, which will be discussed in terms of those most closely resembling features that might be expected from the discipline and those that are idiosyncratic to the individual; (b) weak defining features, which approach those of the stronger type discussed in item (a); (c) characteristic features, which can include more generalized features and attributes; (d) prototypes, which are exemplars that the children identify as their first idea generated when they think of machines or as the example they identify as most typical of machines; (e) exemplars, which are specific examples of machines; (f) relations, which are ideas that establish links with people, the environment, or different features or attributes of machines; (g) emotions-values-aesthetics; (h) metaphors and analogies; and (i) narratives or stories and fantasy.

[Insert TABLE 3 About Here]

A part of the context maps task is to link the items listed on the maps with lines and then to label the nature of the relationship between the items linked by the line. Constructing links, especially labeling them is generally a difficult, if not unsavory, task for children. In the pre-unit context maps only seven children constructed links, and of those only three children labeled their links. On the other hand, in the post-unit maps 23 children constructed links and eight of them labeled at least some of their links (five labeled all links and three labeled some). The labeling of links requires the identification of relations among the context map items and then the construction of a phrase that describes these relations. Table 3 summarizes the types of labeled context map links in both the pre- and post-unit maps. The types of links are categorized by their complexity. The first category, "Lists of Items from Within a Single Type Category", consists basically of links between items of a similar type (see Table 4 for examples). The second category lists links that connect items between characteristic feature categories or between characteristic feature and exemplar items. The third category lists more complex links that connect two or more categories of items with at least one being a non-exemplar or non-characteristic feature category. For instance, one labeled link of EVAs - Examples - Locations - Properties contains EVA items that are neither exemplar or characteristic features (see Table 4 for examples). The numbers appearing in the "# Links" column correspond to the number of students. The numbers in the "# Items" column indicate the total number of items linked across all students with a similar type of labeled link.

[Insert TABLE 4 About Here]

An examination of the nature of the labeled links suggests a view into the complexity of conceptual understanding. The connecting of similar items, a simple classification process, is not as complex as links that cross categorical boundaries. For example, the "components" link labeled "body parts" with the items "wheels" and "legs" is a fairly simple grouping of similar items. On the other hand, "action--components--power source" links the label, "things it has to have to work", with the items "electric", "spring", "buttons", "gears", "solar power", "steel", "metal", "copper", "bolts", "plastic", and "parts." This labeled link demonstrates a more complex understanding spanning a variety of different elements. In the third major category of the Table 4, the links expose even more complex understandings that may include a wider range of meaning. As in the example categorized as "EVAs--examples--locations--properties" and labeled "green indicates things that can help but are not needed" (the student color-coded his links) is linked with the items "weird", "stupid", "weird things", "smart", "homemade", "not high tech", "high tech", "VCR", "fun for people", "heavy", etc., the understandings and aspects of meaning are combined within the notion of machines that can be helpful, but are not necessary. The relationships in this particular example are much more provocative than those of the more simplistic links.

In addition, Tables 3 and 4 suggest a post-instructional change in the children's ability to formulate explicit relationships among their context map items. The number of students labeling their links, as well as the number of items contained within the links and the number of different types of items linked all increased. Whether this is due to the instruction, experience with context mapping, or other factors is difficult to determine.

The complexity of understandings is exposed further in the written definition tasks and interviews. In Table 5, Amanda's pre- and post-unit definitions show a significant continuity of ideas. Machines continue to be thought of as electrical with noisy motors. As mentioned earlier, Amanda's idiosyncratic defining features of machines are that they make noise and contain wires. She's added movement in her post-unit definition. In addition, she has identified a tractor as being her prototypical example of machines after instruction. The ideas that may have resulted from participation in the instructional activities include the notion of purpose (that machines "should do something") and the idea of simple machines with screws and wheels as examples. These newer added ideas are relatively superficial to her primary understanding of machines, but they do demonstrate change. Such change is not a replacement or major restructuring of understanding, but the addition of new information.

[Insert TABLE 5 About Here]

In Table 6, Joe tries to explain how a hand-drill works. In the initial interview, he demonstrates a knowledge of some of the technical terms associated with simple machines. In the second interview, he uses the same terms and adds "wheel" and "bit", as well as "spiral" to describe the structure of the bit. In the second interview, his description of how the teeth of the gear fit together is more explicit.

In Amanda's interview segment about the hand-drill (Table 7), her conceptualization of machines seems to have changed to accommodate simple machines. In Table 5, we see that she maintained the primary notion of machines being electrical, even though she mentioned simple machines. In this case, she applies the concept of simple machines when presented with a hand-drill. However, the richness of her understanding is limited. She mentions the term "inclined planes" when asked what she meant by "little wedgie things" (teeth of the gears). In the initial interview, hand-drills were not machines, because they do not have wires and that the hand-drill "just doesn't look like a machine." In the second interview, when asked what kinds of simple machines (in response to her mentioning of the term) are evident in the hand-drill, she responds with "unelectronic drill". Although she has gained some of the vocabulary, she has not developed an extensive or coherent understanding of the terminology and concepts.

[Insert TABLE 6 About Here]

The hand-drill interviews (Table 8) with Andrea (who the teacher identified as being academically gifted) and the pre- and post-unit definitions (below), however, show the development of a more extensive and coherent understanding in some ways, yet still vague in terms of the terminology and concepts involved with simple machines. In her definitions, she moves from something that's not natural, not necessary, and needing button pushing or controlling to something that (a) helps or entertains; (b) works mechanically, electrically, or with the human hand; and (c) can pollute:

Pre-Unit Definition	**Post-Unit Definition**
.A machine is something that's not natural. We don't need a machine, it just makes things faster and easier, or it gives us pleasure. It works on its own except if it needs button pushing or controling (sic). That's what I think a machine is.	A machine is something that was not here at the beginning of the world. It is something made by man to help, entertain or save time. A machine can work machanically (sic), electrically, or even with the help of the human hand. Some machines we have in our home that we might not even think is (sic) a machine are eggbeaters, T.V., and things that help us do things that might not have been able to do. I think machines are very hellpful (sic), but sometimes they need harmful things like gas which when it has been used, comes out as exaust (sic) and pollutes the air.

She maintains the notions of "manmade" or not natural and saving time or making "things faster" in her second definition. However, in the hand-drill interview, she moves from a vague description of how the drill works in the initial interview to a description that includes the term "axle" and a description of how the gears fit together, even though she did not use the terminology from the unit.

[Insert TABLE 7 About Here]

[Insert TABLE 8 About Here]

If we return to the adaptation and extension of Keil's (1989) delineation of conceptual structure, we can examine the change in children's conceptions of machines (through their written and oral definitions) from a different perspective. In Table 9, Kate's definitions lack defining features that correspond to those expected within a formal knowledge framework. Portions of those aspects of what have been categorized as characteristic features, however, may be idiosyncratic defining features, such as "gears and opening body parts" in the initial definition and metal, gadgets, and "on and off button" in her post-unit definition. Personal values are apparent in her reference to machines being a "piece of junk: if they are "rusty" and "moldy". However, the uniqueness of Kate's definition lies in her narratives and metaphor (which are particularly anthropomorphic in the pre-unit definition). Her human-like robotic machine in the initial definition is embedded in the notion of relationship ("wouldn't to have a machine for a parent") and of independently operating worker ("machine would do your chores"). In the second interview, her story has changed in character. Not only does she identify using her imagination (metacognition), but she focuses on historical ("knight in armour") and possibly realistic ("evil villan" [sic]) characters as being machines. She also includes an example of an invention ("washable sunglasses with wipers"). The conceptual analysis of Kate's definitions suggests a personally distinctive style or approach to thinking and working with ideas. Very little evidence is provided for changes in her formal conceptualizations of machines after instruction. Her preferred approach is in the realm of fantasy and imagination.

[Insert TABLE 9 About Here]

A conceptual analysis of Mel's definitions provides a view of the development of a richer, more extensive, and coherent understanding of machines. Initially, Mel's definition of machines was embedded in emotions-values-aesthetics, with vague references to machines as utensils (which moves in the direction of a weak defining feature) and being metal and electronic (characteristic features). However, after instruction, all of his expressed ideas were more extensive and cohesive. Two aspects of his definitions (written and oral) were more developed defining features, although still somewhat weak in terms of formal knowledge. In his post-unit definition under characteristic features, he continues to mention metal, but here he extends this notion to analogy with biological organisms (in particular, animals). His primary exemplars, which in some sense could be prototypical (however, there is not enough data to establish this particular categorization), are "biologicle (sic) beings" and people. The analogy between a crane and people is further elaborated (in response to my question that probes into his already mentioned analogy between people and other machines) under the metaphors and analogies section of the Table 10. His reasoning through the development of the analogy demonstrates a more extensive and cohesive understanding of machines from the more contemporary, technological perspective and from the traditional perspective of simple machines.

[Insert TABLE 10 About Here]

Student Discourse

In this section, we will draw upon the work of Cortazzi (1994); Gee (1994, April); Kuhn (1989); Morrison and others (1993, April); and Warren, Rosebery, and Conant (1994, April) for an analytical framework to examine children's conversations. Three categories of discourse types will be used: (a) story-telling, (b) school knowledge or "correct answers", and (c) sense-making. Sense-making can further be broken down into "everyday" sense-making and scientific sense-making (Gee, 1994, April).

In some of the previous excerpts of students' conversations, we have seen a wide range in their ability to articulate ideas in a coherent and cohesive fashion. In Table 10, Mel's post-unit interviews were among the more articulate. They demonstrate a substantial change from very brief and vague statements to more extensive and detailed efforts at expressing his concept of biological organisms as examples of machines. However, his post-unit discussions fall short of what Gee (1994, April) refers to as scientific discourse. Under the heading of "Weak Defining Features", Mel mentions that machines are "made for a purpose" and that "some purposes are more complex or more complicated. He supports this notion of purpose with an example of a crane ("crane's purpose is to lift things and make life easier") and adds a further statement that expands on the notion of making life easier ("If we didn't have the crane, we'd have a heck of a time trying to get boats in the water"). He has attempted to articulate the notion of purpose as a characteristic of machines, but has some difficulty in expressing this in a way that is explicitly defined. The more general sense of purpose is vague ("more complex or more complicated"). "Making life easier" is also vague (what aspects of life are being referred to?). In addition, the specific example of the crane does not address the mechanisms involved in making a particular task ("lifting" in this case) easier.

In most of the hand-drill interview segments, including those provided previously in this article, the students' explanations tended to be vague, if not confusing. One example from a more free-form classroom conversation with a group of children working with rack and pinion gears is particularly striking. The children were confused about the activity and requested my help. After interpreting the instructions for them, I told them that many cars use a rack and pinion as a part of the steering mechanism. I demonstrated this by putting my fingers, representing the steering column, in the center of the pinion gear and turning the gear to the right. All of the students in the group immediately picked up on the problem that when I turned my hand to the right the rack moved to the left, which did not correspond to turning the steering wheel to right and having the wheels turn to the right. However, their expression of this problem was not well articulated, but rather a mixture of exclamations of surprise, hand movements, and vague references with "this thing" and "that". I then placed two circular gears, representing wheels, in front of the rack. I repeated the demonstration and, quite by accident, hit the gears (wheels) with the rack. When the two wheels turned to right, the students responded with exclamations of insight (ohs and ahs). They proceeded to try to explain how the steering mechanism might work in a car, but again their articulation was vague. Only by watching their hand movements in conjunction with their verbal expressions was it obvious that they were "making sense" of the mechanism. This particular example relates to what Gee (1994, April) refers to as student cognition outrunning their language. Gee goes on to say that,

> what counts as 'scientific thinking' is not a private mental act, it is a move in the 'game' of science, and that move is made in and distributed within the coordination of language, acts, interactions, values, technologies, symbolic expressions, and objects that constitutes the Discourse of science. (p. 7, emphasis in the original)

In this case, the students' discourse was one of acts and interactions between themselves, myself, and the objects. The verbal discourse was vague, but the non-verbal expressions were not.

Story telling is particularly apparent in Kate's discussions of definitions (Table 9). Although her stories were imaginative, other story-telling examples are related to personal experiences. For example, in Andrea's post-unit interview, her ideas are related to experiences she has had with machines:

> **OK. What are machines used for... in general?**
> Like I said... to help, entertain. Is that what you mean?
> **Yeah.**
> OK, so... like a TV that entertains you. A radio and tape player. And to help you like, uh, tools and appliances and things like that. And at the same time, it would take a long time to wash with your hands [clothes?], but you use a washing machine. Otherwise, there's a washboard.
> **That's not something you like to do?**
> No. (Laughs)

In this example, Andrea responds to the question, "what are machines used for", by relating uses of specific machines with which she has had experience. There is little evidence of any school knowledge, let alone sense-making, in her conversation.

In Table 11, two segments of a conversation within a group working with pulleys is categorized into "school knowledge" discourse and "sense-making" discourse. In the first segment, Lori and Mike are reading and discussing their answers to questions from the activity bins. The discourse is characterized by an emphasis on the terms and ideas focused on in the activity instructions. In both of the children's discourse, elements of story-telling are also apparent. Lori's statement, "If you didn't have the wheels... wouldn't carry the chairs properly," relates the school knowledge elements of wheels (referring to pulleys) to the analogous situation presented in the activity of a ski lift. In Mike's statement, his explanation of school-type knowledge is structured with the linear flow of a story.

[Insert TABLE 11 About Here]

Later in the activity, Nathaniel, Tim, Lori, and Mike are engaged in setting up a pulley and clothesline to move a pail. In this segment, the students are contending with a technical problem of getting the apparatus to work. They are actively discussing the problem and how to solve it. Mike brings in school-type knowledge, but within the context of making sense of the problem. Although his notion of "G-force" is not necessarily appropriate to the problem, he is still engaged in using this concept to make sense of what he views as the problem. However, in this particular example of sense-making, the discourse, once again, lacks the rigor one might expect to see when clearly defining a problem and the ideas and concepts involved. Although Mike attempted to focus on the idea of "force", the other students did not engage in considering this idea. And, even Mike's ideas were vague in how "G-force" was related to the problem at hand.

Although there were glimmers of scientific sense-making discourse among several of the children, most sense-making conversations and written expressions were more heavily embedded in everyday language. However, most students fell far short of engaging in any kind of sense-making dialogue. The dominant modes of expression involved stories (both fantasy and real) and descriptions of school-type knowledge.

Discussion

The instructional unit did not have a dramatic impact on children's views of machines. Although they spent most of the time working with simple machines, the concepts involved with this topic have not been fully integrated, if at all, into the students' understandings of machines. Certainly, the students' view of the activities as a game, as suggested by Mrs. Landry's observation, may have had a significant impact on their learning. In fact, the nature of the activities in the bins may have fueled this kind of an approach. We saw, in Table 11, how the students required written responses to the activity questions produced school-type knowledge responses. Yet, when the students were engaged in their own inquiry into the problem at hand, they acted more like young scientists trying to make sense out the problem situation. According to Rogoff (1990), encouraging children to engage in problem solving dialogues can have a positive impact on conceptual development. Unfortunately, there were far too few opportunities for children to engage in these types of sense-making and problem-solving discussions.

A major part of sense-making, however, involves the ability of children to articulate their ideas. Mrs. Landry's reflections on the unit, in particular her statement that "they couldn't put it into words what they had learned or the reasoning behind it....", suggest that the major parts of the problem are vocabulary and logical reasoning. Acquisition of technical vocabulary certainly seems to be a factor, as we have seen in the pre- and post-unit definitions and interviews. However, lack of technical vocabulary does not necessarily preclude using other terms in the students' explanations. Amanda used "wedgies" or "wedgie things" to describe the teeth of the gears, as did other children using the same or similar terms. However, the problem seems to extend beyond vocabulary to skills of reasoning and of clearly articulating their ideas.

This problem of reasoning and articulating seems to correspond, in some ways, to conceptual organization. Without clearly defined and articulated defining features and other aspects of conceptual understanding, students may find the task of reasoning and talking about problems to be difficult and frustrating. Although a number of students generated metaphors and analogies in their thinking about machines, in most cases, they were not well developed and articulated. When these analogies were well developed, as in the case of Mel, the ideas expressed were more coherent and cohesive. The inclusion of relations may also contribute to the development of more sophisticated conceptual understandings. Although some relations are weak and ill-defined, as may be the case with Mel (see Table 10), they have the potential to extend the richness of understanding and meaning. The beginnings of this can be seen in the students' context maps, definitions, and interviews where they refer to some machines emitting pollution or to how certain machines are useful in specific contexts. The generation of characteristic features and exemplars (including prototypes) tend to be dominated by the idiosyncratic and social experiences of the children. Reliance on these aspects of conceptual development alone does not contribute significantly to the development of extensive and coherent understandings.

The explicit articulation of ideas, as described by Gee (1994, April), in a process of socially constructing and reconstructing knowledge claims represents what Green, Dixon, Lin, Floriani, Bradley, Paxton, Mattern, and Bergamo (1992) and Warren, Rosebery, and Conant (in press) suggest is the acquisition of literacy or literacies. Literacy, in the case of science learning, has to do with developing the ability to communicate (in a variety of ways) ideas, clearly and coherently. The ideas, as well as the communication, are situated in the contexts of science, everyday personal experiences, the social grouping, and the particular culture group or groups. The ideas are constructed and reconstructed both individually and socially through a process of social negotiation in the classroom. However, in developing scientific literacy, the ideas and communication need to "moved" into the context of science. They need to be moved away from what Gee refers to as everyday language towards science talk.

At the same time, students generate rich ideas in the context of everyday language and everyday experiences. Emotions-values-aesthetics are one such example. They are immediate and sometimes extensive reactions to the world, including machines. They are unavoidable. In some ways, EVAs can interfere with conceptual development. They are familiar and comfortable ways of reacting and of developing opinions and views of the objects and events experienced by the child. In Table 10, Mel relied heavily upon EVAs in his definition of machines in the pre-unit tasks. However, there was no evidence of these EVAs in the post-unit tasks. Such a lessening in the reliance on EVAs coincided with an increased sophistication in conceptual development.

On the other hand, EVAs, interpretive frameworks, such as anthropomorphism, and narratives, as well as metaphors, can offer possibilities for children to develop understandings and products in contexts other than science. For elementary children, it may be important to capitalize on such alternative areas of understanding and production. In the instance of Kate (Table 9), supporting her imaginative ideas can be very important in maintaining her interest, motivation, and self-efficacy. She could be encouraged to develop some of her ideas into story books or other products. However, the difficulty lies in trying to encourage alternative meanings and understandings, while encouraging the development of more sophisticated conceptions and scientific discourse.

As Gee (1994, April) points out, everyday language "has given rise to some of human beings' 'deepest' insights into the human condition.... [It] allows for juxtapositions of images and themes in the creation of patterns..., [and] is very often an extremely powerful device in its own right" (p. 5). He also suggests that "everyday language is much better, in fact, than the language of science in making integrative connections across domains" (p. 6). In earlier articles (Bloom, 1992a; 1992, April), I have suggested that when we look at children's meaning-making (contexts of meaning), we find a great deal of potential for developing multiple understandings and perspectives. However, the trap of such an integrated approach to developing multiple understandings is that of relativism. Relativism in terms of multiple understandings of the world, which are apparent across different cultures, religions, ethnic groups, as well as individuals, can provide highly functional explanations of physical events (Lewis, 1992). On the other hand, when working with children in the classroom, unbridled relativism serves only to propagate further confusion and to lead to the development of weak conceptions and low level scientific discourse. If an integrated approach is taken, then it is important to help students develop an understanding of how to determine the contextual appropriateness of the ideas they generate. At the same time, teachers need to focus on (a) the development of scientific discourse by down playing the "game" nature of many classroom activities and (b) the development of more extensive and coherent conceptual understandings.

Implications for Classroom Practice and Teacher Training

As mentioned, the teachers involved in this project chose to design their unit around simple machines. However, rather than focusing on a specific topic, such as simple machines in this case, a more robust approach could look at the problem of what are machines, in general. Having students socially construct and reconstruct definitions of machines could provide opportunities for exploring and negotiating further knowledge claims. As children propose ideas, like "they make things easier", teachers can have children explore what they mean by making things easier. Are there exceptions to this idea? Does "easier" mean different things for different machines, for different people, different cultures? Of course, these questions can provide the opportunity to expand on the breadth of what objects are machines, such as, introducing simple machines.

Students need to be engaged in the problems of defining and articulating the scope, concepts, and principles of the topic at hand. In the case of machines, some students said that they do work. How does the notion of work differ between computers and a crane? Do all of the machines they list do work? What about televisions? The concept of work can be explored in detail, from the traditional view associated with levers, gears, etc. to their notion of work as related to computers. As students come to the point where appropriate information is needed to proceed further with their investigations into the nature of machines, the teacher should provide appropriate concepts, facts, or formula. During the present study, one student was interested in the difference in the number of turns made by the crank and the gear in a hand-held egg beater. We used yellow chalk to mark the gear and then counted the number of complete revolutions of the crank and gear. A ratio was determined, but was left at that. This investigation could have been extended to compare the ratio of different gears with the performance of different tasks. This type of task could be embedded in the question of which gear (1, 2, 3, 4, or 5) allows a car to go fastest and which gear is best for pulling a heavy trailer up a hill. As the students construct their principles of gear ratios and work, they can be asked to try to apply these principles to pulleys, and so forth. As questions are posed by students, teachers need to be prepared to expand on these questions in ways that allow students to construct meaningful principles, concepts, and theories.

Essentially, the classroom practice needs to be viewed as a process of socialization into a community of inquirers with the characteristics of scientific thinking, knowledge construction, and, argumentation, rather than instruction into how to do these processes (Gee, 1994, April; Resnick, 1989; Warren, Rosebery, & Conant, in press). As Warren and others suggest,

> fundamentally, the idea is to place question posing, theorizing and argumentation at the heart of students' scientific activity. Students explore the implication of the theories they hold..., examine underlying assumptions, formulate and test hypotheses, develop evidence, negotiate conflicts in belief and evidence, argue alternative interpretations, provide warrants for conclusions, and the like. (p. 9)

In order for this process to occur, the teacher needs to model the approach. Students become apprentices in the process of becoming a community of young scientists. Although the teacher, Mrs. Landry, in this study did model the approach to some degree, the impact may have been interfered with by the nature of the activities and the narrow focus around which the activities were designed. The successful creation of a community of young scientists needs to be thought out more carefully beforehand and monitored (reflected upon) throughout the year.

However, the lack of background in science may be a limiting factor for most elementary teachers when confonted with possibilities of extending investigations from student questions. But, even with a substantial background, teachers may find it difficult to capitalize on opportunities arising from student questions. Teachers not only need to have enough understanding of science to know where the path of student inquiry may lead, but they need to develop the skill of recognizing such opportunities and to develop their understanding of the material to the point where they can provide additional investigations and any necessary information. This situation is problematic for most elementary teachers, who have had little training in science content and who have had far to little, if any, exposure to appropriate pedagogical practices that support such approaches. How to address this problem is beyond the scope of this paper, but is an important area for further research.

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Appendix A
Machines Unit Topics

Springs and Stretchy Things
wind-up alarm clock
elastics

Inclined Plane
force
elastic
wedge
ice scraper
trowel
wire cutters
chisel
knife
toothpicks
nails
screw
drill bit
U-clamp
nuts
bolts
zippers
plow
ax
locks
can opener

Gears
egg beater
egg whisk
straight teeth = spur gears
angled teeth = helical
straight gears = rack and pinion
toy engine

Sticking and Slipping (Friction)
energy
power from:
gasoline
electricity
water
wind
pushing force
windmill

Wheels and Axles
Medieval wagon inventor
invention
steering wheel
bicycle wheel
wheel on clothes line
elastic

Pulleys
ski lift
clothes line
escalator
elevator
tower crane
trolley
hoist
shadoof
fork-lift truck
counterweights
block and tackle

Levers
nutcrackers
bottle opener
excavator
hammer
nail clippers
pivots
hinges
weighing machines
manual typewriter
grand piano
platform scales
beam scales
wheelbarrow
nail extractor
bottle opener
pliers
nutcrackers
hand cart
fishing rod
tweezers
fulcrum
scissors
parking meter

Appendix B

Pre- and Post-Machines Unit Numerical List of Context Map Items

Pre-Machine Unit Context Map Items	
19	automobiles; car (s)
12	train (s); turbo train
12	T.V. (s)
12	computer (s)
11	airplane (s); planes
10	truck (s); slow trucks
10	electric, -ical, -icity, -tronic
9	V.C.R.
9	radio
9	metal
8	stove (s)
8	phone; telephone
8	Nintendo
8	fast
7	work(s); -ing; you -- with them
7	Sega; Sega Genesis
7	dryer (s)
7	big
7	air conditioner
6	wires
6	washer; washing machine (s)
6	stereo; stereo system
6	smart
6	robot (s)
6	moves; --quickly; -ing
6	machine gun (s)
6	lawn mower
6	help (s); -ing; they --you; --you fast
6	guns
6	elevator
6	dishwasher
6	Christmas light (s); Xmas light
6	C.D. player
5	Zambonie
5	vans
5	space craft; - ship; - vehicle
5	remote; -control; - - for T.V.
5	overhead; overhead projector
5	motor cycle
5	lights
5	lamp (s)
5	jet (s)

Post-Machine Unit Context Map Items	
14	electric, -ical, -icity, -tronic
13	car (s); they take you places (automobile)
12	lights
12	help(s); -ers; --out; -- a lot; --do things; --in a way
11	wires; it has ... wires ; some run on wires ....
10	wheels; moves by
10	TV
9	VCR
9	batteries (has --; uses --)
8	work (s); -ing
8	van (s)
8	manmade
8	computer(s); helps to write school work
7	move (s); -ment; -- by wheels and electricity
7	metal; made of; mostly made out of
7	airplanes; plane (s)
6	train (s)
6	robot (s)
6	gas
6	fast; goes fast and well
6	clock (s)
6	buttons
6	big
5	washer; washing machine
5	steel; made of
5	radio
5	noise
5	microwave (s)
5	loud; it's sometimes loud!
5	helpful
4	watches
4	truck (s)
4	smoke
4	slow
4	runs; -- for a long time; some -- on ...
4	power; has lots of power
4	phone
4	Nintendo
4	motorcycle (s)
4	heavy
4	games; lets you play --; some ... you can play --
4	fun; -- for people; it's --

5	fun; -- hours
5	fridge; refrigerator
5	fax; fax machine (s)
5	clock (s)
5	button (s)
4	wheels
4	watch
4	useful
4	tape player; tape recorder
4	tank (s)
4	tall
4	Super Nintendo
4	strong
4	small
4	plug
4	motors
4	microwave (s)
4	keyboard
4	heavy
4	heater (s)
4	gas
4	fly; -ing
4	doorbell
4	cut (s); -ing
4	copy machine (s); photocopier
4	building(s)
4	boat (s)
4	battery, -ies, battery operated, car --
3	ugly
3	tractor
3	toy (s)
3	snow blower
3	remote control car (s)
3	pull (s); -ing; -- stuff
3	paper
3	nice
3	light (s) up; -walks
3	Game Boy
3	fan
3	escalator
3	engine (s)
3	electric toothbrush
3	dig; -ging
3	carries; carry stuff
3	black
3	baby loves to talk; (--- hearts)

4	fridge
4	dryer
4	cook (s)
4	coffee maker
4	bolts
3	vacuum; vacuum cleaner
3	typewriter
3	toys
3	tape player; tape recorder
3	Super Nintendo
3	stove (s)
3	spring (s)
3	solar power
3	small
3	pollution
3	plugs
3	plastic; made of
3	overhead
3	oven (s)
3	noisy (very --)
3	motor (s)
3	good
3	gears
3	factory (-ies)
3	CD player
3	bicycle; bike
3	bad
3	vacuum; vacuum cleaner
2	video camera
2	useful
2	used everywhere; they're everywhere
2	ugly
2	toaster
2	tanks
2	stupid
2	snow blower
2	rusty
2	rocket (s)
2	piano and other instruments
2	pencil sharpener
2	oil
2	nice
2	muscle power
2	motorboats; boat (motor)
2	molds
3	light

3	answer (-ing) machine
3	alarm clock
2	writes; -ing
2	water tap; tap
2	water
2	videos
2	video camera
2	vending machine
2	typewriter (s)
2	travel
2	toaster (s)
2	tennis ball spitter
2	super duper double looper
2	stinks
2	steel
2	smoke
2	smell (s)
2	slow
2	silver
2	shredder
2	shred (s)
2	saw
2	roller coaster
2	rocket; rocket ships
2	repair
2	pitching machine
2	pictures
2	parts; has rusty parts
2	P.A. system (s)
2	oven
2	oil
2	neat
2	make(s) things
2	make
2	light
2	jeeps
2	gross
2	garage door opener
2	games
2	Game Gear
2	float
2	fireplace; gas fireplace
2	factory
2	explore(s)
2	electric pencil sharpener
2	lawnmower (s)
2	keyboard
2	Game Gear
2	Game Boy
2	FAX machine
2	energy
2	dishwasher (s)
2	dark
2	copier; photocopier
2	cools
2	connects
2	cleans; clean up
2	catapult
2	can opener (s)
2	camera (s)
2	bus
2	bulldozer
2	build; built
2	boom box
2	blender
2	axle(s)
2	air conditioner
1	you don't have to watch it, you can leave and do another thing
1	you don't have to do anything
1	you can work it by yourself
1	you can make it stop
1	worn out
1	workshops
1	work plants
1	water pump
1	warns you if gas is low or it's been on for over two hours
1	war
1	walk
1	volts
1	video games
1	video games
1	very large
1	used around the world
1	use
1	UFOs
1	twists
1	turn
1	transportation

2	electric guitar
2	dumb
2	drill (s); drilling
2	door (s)
2	cords
2	cooks; -- food
2	computer chips; microchips
2	colors
2	coffee machine (s)
2	cleans
2	camera
2	bumpy
2	brown
2	brains
2	body shop
2	blow dryer
2	blades; sharp blades
2	bike (s)
2	baseball spitter (s)
2	baby shiver (s)
2	Atari
1	yo-yo
1	you can work anytime
1	works until it wants to
1	work plants
1	windshield wiper
1	windows
1	wind <srocor>
1	wigs
1	white
1	weedeater
1	war
1	video cassette
1	V.C.R. tape
1	us
1	turn into things
1	Turbo Grafix 16
1	tuning fork
1	troll company
1	traffic lights
1	track
1	toy lights
1	tools
1	tools
1	toilet
1	toaster oven
1	they're watchful (burglar alarm)
1	"they're not a toy"
1	they're modern
1	they make things easy
1	they do stuff for you
1	The Enterprise
1	talks to you
1	system
1	stores have machines
1	stereo
1	step to make
1	steam
1	sprinkler
1	sprinkler
1	spines
1	space crafts
1	sometimes causes trouble
1	something with moving parts
1	some ... attached to a remote control
1	soft
1	smash
1	smart (very --)
1	small
1	sink
1	simple machines
1	silver
1	signals
1	shuts on and off
1	serves a purpose
1	sensors
1	self-working
1	Sega Genesis
1	sections
1	science
1	revolve
1	recycles
1	record player
1	pump
1	pulleys
1	price
1	police
1	plugs things in
1	plays music
1	play
1	pivot
1	phonics

1	time
1	thoughtful
1	terminator
1	tell time
1	tax
1	tapes
1	talks
1	talking stall
1	talking scale
1	talking dolls
1	talking Barbie
1	talking <grilesnall>
1	switch to turn on
1	super duper double looper
1	Super Sega
1	stupid
1	stop watch
1	stop
1	steamroller
1	stars
1	stamp
1	spot light
1	spinning tops
1	speed
1	speaker
1	space shuttle
1	sold
1	solar power
1	small
1	skate sharpener
1	sirens
1	sinks
1	silence
1	sewing machine
1	service
1	scoop
1	science
1	saws
1	satellite dish
1	satellite
1	rust
1	runs
1	rotor copter
1	robotic voices
1	robot ships
1	roads
1	phasers
1	people
1	pens
1	pay
1	parts; parts and things that move
1	outdoor
1	old
1	obeys
1	nuts
1	not high tech
1	not heavy
1	not hard to get to work
1	not all people use them
1	nails
1	mother board
1	more than one of them
1	models
1	messages
1	message
1	masher
1	many things
1	makes toys
1	makes food
1	make things louder (like your voice)
1	make things faster
1	make things
1	make big
1	made by Japan
1	machines are used a lot
1	machine talk
1	lights
1	light
1	levers
1	less
1	legs
1	lasers
1	keeps your money
1	keeps you in shape
1	it helps you do work
1	iron
1	inventors
1	indoor
1	if food it stores it
1	huge
1	homework [makers]
1	homemade

1	ring machine
1	right handed
1	remember stuff
1	red
1	records
1	record player
1	read stories
1	radio control truck
1	radio control tractor
1	radio control car
1	pushing
1	pump
1	protective
1	problem solving
1	power tools
1	power saw
1	Potty Patsy
1	polite
1	police
1	plug socket
1	plates
1	plastic
1	plan
1	plain
1	pizza place
1	people
1	pens
1	pencils
1	pencil crayons
1	pecan picker-upper
1	paper cutter
1	overhead electric grater
1	orange squeezer
1	open to change battery
1	office
1	obeys you
1	nuts
1	numbers
1	noisy
1	Nintendo game
1	movie camera
1	motor pool blower
1	motor boat
1	motor bike
1	month
1	monsters
1	high tech
1	have fun
1	has a timer ...
1	has ... rings
1	hard
1	handles
1	hand-working (like eggbeater)
1	guns
1	golf cart
1	go up down
1	gives you things
1	gives you a big electricity bill
1	gives light
1	get rid of things
1	gas station
1	garbage truck
1	game for Nintendo
1	gadgets
1	furnace
1	flyers
1	fly
1	flashing
1	fire
1	finished
1	finds
1	except for TVs, microwaves, Nintendos, telephones, hairdryers, Game Boy, refrigerators
1	entertains you
1	energetic
1	electronics
1	electric can opener
1	Dust Buster
1	dumb (stupid)
1	drug machine
1	drive
1	dries
1	done
1	don't work
1	doesn't run out [of gas]
1	disk
1	delivers
1	cuts things
1	crane
1	cracks
1	cords
1	copper

1	Minute maid machine
1	mining dryer
1	microscopes
1	microphone
1	merry-go-round
1	meltdowns
1	materials
1	markers
1	malfunction
1	magnetic
1	magic potty baby
1	machines go and start
1	machines are different shapes
1	machine store
1	lynx
1	loud
1	load
1	listening
1	liposuctions
1	light switch
1	lie detectors
1	levers
1	letters
1	latches
1	laps
1	knobs
1	kites
1	jack hammer
1	iron
1	invisible
1	inventors
1	invent
1	information
1	humungis
1	hot
1	hospital
1	horn
1	homes
1	helpful
1	helicopter
1	height
1	handyman (or lady)
1	handle
1	hair elastics
1	gum dispenser
1	green
1	computer printer
1	companies make machines
1	companies
1	communication
1	cold
1	coffee pot
1	cleaners
1	clean your room machines
1	choppers
1	cash machine
1	candy
1	calls people
1	burn
1	bright
1	breaks
1	brain
1	boat
1	big and small
1	beeping
1	battles
1	batting cage machine
1	arms
1	answering machine
1	an electrical object
1	all machines are alike
1	a moving object
1	<viecats> car
1	<pipelremerv>
1	<losey>
1	<eregs>
1	<brig>
1	<anelmo>

1	gray
1	gold
1	goes to far places
1	glue
1	glow
1	glasses
1	glass
1	glass
1	giant
1	garden hose
1	garbage disposal
1	function
1	fuel
1	Frankenstein
1	flashlight
1	fish tank
1	ferris wheel
1	eyes
1	emergency
1	electric roller skates
1	electric message carrier
1	electric knife
1	electric fence
1	electric broom
1	elastic
1	driving
1	drill
1	drawers
1	donuts
1	doesn't lie
1	different kinds
1	delivers
1	dangerous
1	curling iron
1	crimper
1	crane
1	cold
1	codes
1	cleans street
1	circuit board
1	ceiling fan
1	cares
1	car batteries
1	cannon
1	can have fun
1	cake machine

1	C.D.
1	buses
1	bump
1	bulldozer
1	brook
1	brings stuff to places
1	bowling alley
1	booms
1	bolts
1	bobcart
1	blow up
1	blender
1	big or small
1	bending machine
1	bake and cook
1	baby alive
1	atom bomb
1	arcades
1	arcade game
1	answers questions
1	androids
1	all different colors
1	air tanks
1	air conditioning
1	air blower
1	<yuirers>
1	<uarts>
1	<Syop>
1	<Slomes>
1	<serv-nam aclen>
1	<pyno>
1	<murduck>
1	<linx>
1	<leav slropen>
1	<fedocaper>
1	<Ctaro>
1	<cover>
1	<cos>
1	<CCP>

TABLE 1

Distribution of Categorized Machines Unit Context Map Items (percentage figures refer to the number of items within a category out of the total of number of items across all children)

Categories	Pre-Unit		Post-Unit	
	%	#	%	#
TOTAL STUDENTS		26		27
TOTAL ITEMS	100.0	880	100.0	677
SOURCE 0.2	2	2.2	15	
GENERAL POWER SOURCE	0.7	6	2.5	17
ELECTRICITY; ELECTRICAL SOURCE	1.6	14	3.5	24
GENERAL CHARACTERISTICS	4.0	35	6.1	41
SIZE	2.2	19	1.8	12
COLOR	1.7	15	0.1	1
OUTPUT	0.3	3	2.8	19
EXAMPLES	53.8	473	37.7	255
GENERAL	0.1	1	0.4	3
TOTAL MECHANICAL	30.3	267	19.9	135
MECHANICAL	14.3	126	8.4	57
MECHANICAL APPLIANCES	2.7	24	2.2	15
TRANSPORTATION	11.2	99	8.7	59
ARMAMENTS; WARFARE	2.0	18	0.6	4
TOTAL NON-MECHANICAL	18.9	160	12.3	83
NON-MECHANICAL	12.0	110	8.3	56
COMPUTERS AND VIDEO GAMES	4.5	40	3.1	21
NON-MECHANICAL APPLIANCES	1.1	10	0.9	6
MECHANICAL OR NON-MECHANICAL	2.0	18	3.1	21
FANTASY	2.0	18	1.0	7
ROBOTS	0.9	8	0.9	6
BIOLOGICAL	0.1	1	0	0
COMPONENTS	8.2	72	13.1	89
FUNCTION; PURPOSE; ACTION	9.4	83	14.0	95
MAINTENANCE	0.7	6	0.8	5
LOCATIONS	1.0	19	2.4	16

USERS	**0.3**	3	**0.6**	4
EMOTIONS-VALUES-AESTHETICS	**5.2**	46	**8.1**	55
ANTHROPOMORPHISM	**1.6**	14	**0.6**	4

TABLE 2

Categorization of Most Common Items on Context Maps (Percentage [%] figures refer to number of children responding with a particular item)

Pre-Unit Context Maps (N = 26)			Post-Unit Context Maps (N = 27)		
%	#		%	#	
EXAMPLES					
73	19	automobiles; car(s)	48	13	car(s); they take you places
62	16	airplane(s); planes; jet(s)	44	12	lights
46	12	computer(s)	37	10	TV
46	12	train(s); turbo train	33	9	VCR
46	12	T.V.(s)	30	8	computer(s); helps write school work
38	10	truck(s); slow trucks	26	7	airplanes; plane(s)
35	9	radio	22	6	train(s)
35	9	V.C.R.	19	5	radio
19	5	lights	15	4	truck(s)
COMPONENTS					
35	9	metal	41	11	wires; it has ... -- ; some run on -- ....
23	6	wires	37	10	wheels; moves by
15	4	wheels	33	9	batteries (uses; has)
15	4	battery, -ies, -- operated, car --	26	7	metal; made of; mostly made out of
FUNCTION; PURPOSE; ACTION					
23	6	help(s); -ing; they -- you; -- you fast	44	12	help(s); -ers; -- out; -- a lot; -- do things
POWER SOURCE					
38	10	electric, -ical, -icity, -tronic	52	14	electric, -ical, -icity, -tronic

TABLE 3

Categorization of Pre- and Post-Machine Unit Context Map Links

Pre-Unit Context Maps	**# Links**	**# Items**	**Post-Unit Context Maps**	**# Links**	**# Items**
Lists of Items from Within Any Type of a Single Category					
			Action	**1**	
Components	**1**	**3**	Components	**5**	**1**
EVAs	**1**	**2**	EVAs	**3**	
Examples	**1**	**2**	Examples	**3**	**1**
			Features	**1**	
			Functions	**6**	**1**
			Location	**2**	
			Opposition	**1**	
			Power Source	**2**	
Properties	**1**	**2**	Properties	**2**	
			Requirements	**1**	
Lists of Items Between Characteristic Features Categories and/or Exemplars					
			Action--Components	**3**	**6**
			Action--Components--Power	**1**	**11**
			Source	**2**	**9**
			Action--Effects	**2**	**4**
			Action--Power Source	**1**	**2**
			Analogy--Components--Energy	**1**	**2**
			Components--Examples	**2**	**5**
			Components--Products	**1**	**2**
			Components--Properties	**1**	**3**
			Components--Source	**1**	**4**
			Effects--Examples--Function--Power Source		
Examples--Features	**1**	**2**		**3**	**9**
			Examples--Functions		
Examples--Properties	**1**	**3**		**1**	**3**
			Features--Function	**1**	**2**
			Function--Power Source	**1**	**4**
			Output--Product		

(TABLE 3 continued)

TABLE 3 (cont.)

Lists of Items Between Categories and From At Least One Non-Exemplar or Non-Characteristic Feature Category

			Components--Physical Context-- Properties --Source	**1**	**4**
Components--Relations	**1**	**2**			
Context of Use--Functions	**3**	**6**			
EVAs--Examples	**2**	**4**			
			EVAs--Examples--Features--	**1**	**11**
			Properties	**2**	**7**
			EVAs--Examples--Functions	**1**	**15**
			EVAs--Examples--Locations-- Properties	**1**	**2**
			Examples -- Physical Context	**1**	**2**
			Examples -- Users		

TABLE 4

Examples of Labeled Links Between Items on Pre- and Post-Unit Context Maps

Time	Category	Label on Link	Linked Items
Links Within Any Type of a Single Category			
Pre	Components	latches	• knobs • buttons • latches
Post	Components	body parts	• wheels • legs
Post	Functions	way it works	• self working • hand working (like eggbeater)
Post	Functions	it is a purpose of machine	• connects • lights • serves a purpose
Post	Power	power	• muscle power • solar power
Post	Requirements	thing you have to use	• phonics • science • brain
Lists of Items Between Characteristic Features Categories and/or Exemplars			
Post	Action -- Components	moving parts	• motors • gears
Post	Action -- Components -- Power Source	things it has to have to work • plastic	• electric • spring • buttons • copper • solar power • parts • steel • metal • gears • bolts
Post smash	Action -- Effects	things that can happen	• breaks • repair • spines [spins] • cracks • build • twists •
Post	Examples -- Functions	they're both things to help you move	• wheels • pulleys • move
Post	Output -- Product	things you get	• messages • sensors • signals • communication
Pre	Examples -- Properties		• wheel • speed • fast • speed
Links Between Categories & From At Least One Non-Exemplar or Non-Characteristic Feature Category			
Post	Components -- Physical Context -- Properties -- Source	made of metal and melting	• factories • melt • metal • hot metal
Post	EVAs -- Examples -- Locations -- Properties	green indicates things that can help but are not needed that much	• stupid • stores have machines • smart • all machines are alike • not high tech • high tech • VCR • heavy • not heavy • not needed • weird • too much • very large • homemade • weird things • fun for people

TABLE 5

Amanda's Continuity of Meaning and Addition of Superficial Information (ideas that are maintained in the post-unit definition have a single underline, ideas that may have been influenced by instruction are double underlined)

Pre-Machine Unit Definition	Post-Machine Unit Definition
A lot of machines use batteries like toys or even some cars so I'd say you could define a machine to be a machine if it had batteries. A lot of machienes (sic) also have motors or engines or something like that because almost all machiens (sic) I know of make a whiring (sic) rumbly (sic) noise wich (sic) is usally (sic) caused by an engine or whatever so if it makes a whiring (sic) noise it's a machine. Some machines are controled (sic) by wires so if it's full of wires it's a machine. That's how I difine (sic) machines.	I think a machine is something with wires and batteries. Machines really should do something. All machines do. They can write or cook or take you places. If they don't move or make noise or anything then they really are not a machine at all. When I first say "machine" the thing that comes to mind is a tractor because it's big, noisy and metal. That is my main idea of a machine but then there are toys and simple machines (wich [sic] we learned about!) like a screw or wehel (sic). Machines can be complicated and confusing but they sure are fun!

TABLE 6

Working With a Hand-Drill: Excerpts of an Interview With Joe

Pre-Unit Interview	Post-Unit Interview
Do you know what that's called? A hand drill? I have a cordless electric drill at home. **...What do you use that for?** Drilling holes in wood and metal.... **Do you know how that works?** Well, there's a pole down here... and it's attached to these gears right here and these teeth fit into it and you turn the handle... and that hooks onto these makes these move and it's attached to this pole makes the drill move and then it drills into something. **Do you want to try it out?** I think it goes this way. **Do you what this part is? What it's called?** The bit? **Yeah. Do you know how that bit works?** I think we need to turn it. Like these things... it's like a screw and it goes into something like... you hold your hand right here... see it'll move your hand up and... but the wood goes up here and when it's turning it'll make a hole in it. **Is this a machine do you think?** Well,... yeah. **What would make that a machine?** Well, it has some gears and it can do things for you. Like you could just do this instead of... instead of like putting a rock there and pushing it and trying to push it in with your hand.	**... Do you remember this?** Yup, I remember that hand drill. **Uh huh. How does it work?** Well... There's this handle is connected to this wheel and on the other side, there are these teeth... **Yeah.** that fit into a gear that has the same teeth that attach to a pole that drives the bit thing ... **Uh huh.** And, then the bit is shaped like this, so when you turn it, when it turns, it digs itself into the wood or whatever. And, see the spiral things, they kinda push it up and ... ...

TABLE 7

Working With a Hand-Drill: Excerpts of an Interview With Amanda

Pre-Unit Interview	Post-Unit Interview

Have you ever seen something like this ..?

No.... What is it?

What do you think?

I don't know. A drill? Maybe drill things...

Try it, if you want....

It doesn't look like it's, oh, yeah it is going somewhere like into the wood....

How do you think it works? Can you explain it to me?

Well you have this thing and that's probably attached to this thing, no that's attached to these two things.

Which two things, let's see?

These two - this and that, the round things.

With little ridges on it? [gears]

Yeah, going round and round and round and round and when you turn those. Oh, I get it, or I think I do; this thing [shaft] comes through this thing and it goes till there [bit].

Okay, from the tip all the way through...

And through there and then those things are attached to this and it's also attached to this so when you turn this thing [crank] it turns those things [gears] so it turns this thing [bit].

Good... How... do you think that works?

To go into the wood you mean?....Well, it's all spirally and... sharp so when you put it down and you start to turn it around all those edges things go down and down... through it so that you get a hole.

What do you think it could be used for?

For drilling holes and you can put nails in the holes to hang things up. You might just want to have a hole in your wall. You might be trying to make something out of wood. I've seen bigger drills and you hook them through like coal and stuff like that and all these sparks come out. I don't know....

...Would you call this a machine?

No.

...Why do you think it's not a machine?

I don't know. Almost all machines have wires, and this has no wires, it doesn't look like it has any wires, it turns all of the other things; it just doesn't look like a machine.

O.K. What's this?

I don't know. Like, it screws in and holds something or something.

O.K. Do you remember this? You don't remember playing with that?...

Oh. It's this thing. And,...

Is this a drill?

Yeah. Cool.

How does it work?

Our drill doesn't work like that. O.K. You turn this thing [crank]... it turns that thing [gear].

What thing is that?

I don't know. This little thingie in there.

O.K.

And then, it just keeps turning and turning from in there... Yup. There's just that little circly thing. And then on both sides, there's these little wedgie things... And then, it just goes right out to this thing. And then when you turn it, it keeps going out this thing... So it goes out and then it goes back in again.

So, ... Do you know the names of any of those parts?

Um... No. Uh, handle?

O.K.

And little wedgie things?

What are those little wedgie things called?

Hmm. Are they like inclined planes or whatever? ....No?

Huh. That's interesting. ...

Hey! You know, I just realized something!

What's that?

These tiny little wedgie things fit right into these other ones. When you turn them, they go right in. So that they fit... Turn them around.

That's neat. So, is this a machine?

A... simple machine.

O.K. Is there, ...What simple machine is it... or simple machines?

I don't know. It's... an unelectronic drill.

An unelectronic drill?

TABLE 8

Working With a Hand-Drill: Excerpts of an Interview With Andrea.

Pre-Unit Interview	Post-Unit Interview

Have you ever seen something like this?

That's what I meant by hand things...And like an eggbeater. That's... a machine, too

Try turning it the other way - see what happens.... Which way works better?

I don't know, I think the first way, it's not going anywhere.

How do you think it works?...

Well, this turns that and something in there makes this turn... and then it just drills down because it's sharp.

...how does that... [drill bit] work?

....When you put it down it makes the wood go away from it....

How's that happen exactly?

...I think if you do this way... see I think it pulls the wood or something... or it just ... when it turns it just sort of makes its way through the wood 'cause it's sharp....

What can it be used for?

Drilling wood, drilling anything like you need to have holes in, ...things maybe that you want to put... like a screw in, you could put this screw on it or something like that and you keep turning and the screw goes in.

Okay, can you think of anything else that works like that?

A cork, a corkscrew.... And the electric drill my dad has. And... barber shop window..., an egg beater so I can make bagels, a clock inside.

How's it like a clock?

'Cause it has those little things that ...

Those little ridges all around? [gears]

Yeah. Inside the clock....

Is this thing a machine?

Yeah, I would call it a machine.... because, you can't just do this with your fingers. It helps you get it in.

Oh yeah .... Do you remember this? This thing here?

Yup... I call that a machine.

OK... Explain.

Well, because when you move this, these little axles, they twist this thing and it drills with this thing. It's just like, instead of taking something yourself and just like turning it, you can just go like this and it goes a lot faster.

OK. How does it work?

Well, if you put it into something and this keeps going in there, it's sharp, so it drills a hole.

OK. What's this part do here ... the part you turn?

I think it's a big axle. I'm not sure about that though. With these little things fit into each other, that turn each other.

What are they called?

I don't know (laughs).

OK. Your father's an engineer, is that right?

Yup. Electrical engineer....

... What other things work like this ?

Egg beaters. Um, and things with a handle, moving the... I don't know. Maybe.... I still think an egg beater. That's why. I don't know.

It does... when it turns. It even sounds like it. (Sound)... And you say that's a machine? Why is it a machine?

Well, because it's like... it saves time and you can just, these little things work together to move this and you just have to go like this and it works a lot faster.

TABLE 9

Conceptual analysis of Kate's pre- and post-unit definitions (written and oral)

Pre-Unit Definitions	Post-Unit Definitions
Defining Features	**Defining Features**
Weak Defining Features	**Weak Defining Features**
Characteristic Features • "A machine is made with gears and opening body parts...." **[see "Metaphors/Analogies"]**	**Characteristic Features** • "A machine is to me a piece of medal (sic) with gajets (sic) to make it work. A machine also has an on and off button on which you use to turn on and off....But if it's new it could mean almsot (sic) anything to me...." • "it's all rusty and moldy and stuff... a machine can be a piece of metal with a lot of gadgets." **[from interview]**
Prototypes (as expressed)	**Prototypes (as expressed)**
Exemplars	**Exemplars**
Relations	**Relations**
Emotions-Values-Aesthetics	**Emotions-Values-Aesthetics** • "A machine to me is sort of a piece of junk if it's all rusty and moldy."
Metaphors/Analogies • "like the stomach is an **opening door**..." **[see "Stories/Fantasy"]**	**Metaphors/Analogies**
Stories, Fantasy • "no heart in a machine arms and legs much like a human and playful and will want to do anything you want to do or walk the dog or clean up after the cat or any chore that you can't do like if you broke your leg the machine would do your chores for you that's what I think a machine is. And I wouldn't like to have one as a parent. Because it would have no heart and wouldn't really care about you because the machine would have no heart that's why I wouldn't want to have a machine for a parent."	**Stories, Fantasy** • "I just have to turn on my imagination.... When I turn on my imagination I could think a machine is a knight in armour or an evil villan in a fight. It could also be very plain like a pair of washable sunglasses with wipers like on a car, and that's a machine to me." **[*** "knight..." and "villan..." are also metaphors ***]**

TABLE 10

Conceptual analysis of Mel's pre- and post-unit definitions (written and oral)

Pre-Unit Definitions	Post-Unit Definitions
Defining Features	**Defining Features**
Weak Defining Features • "...machine just be a utensil." **[from interview]**	**Weak Defining Features** • "A machine is a structure or tool created by man it is not a rock or a book.... " • "they're made for a purpose.... Like... some purposes are more complex or more complicated ....the crane's purpose is to lift things and make life easier for lifting things. If we didn't have the crane, we'd have a heck of a time trying to get boats in the water..." **[from interview]**
Characteristic Features • "Well, metal and the electronics I guess... **[So everything metal and electronic is a machine?]** Not necessarily... sometimes... " **[from interview]**	**Characteristic Features** • "they're metal... they get people going somewhere... sort of way we're machines ...Well, see how machines have... metal and everything, we have bones and muscles... if we didn't have bones or muscles, we'd just be lying down on the ground unable to do anything." **[from interview]**
Prototypes (as expressed)	**Prototypes (as expressed)**
Exemplars	**Exemplars** • "All biologicle (sic) beings are machines because they have certan (sic) movements functions or actions." **[see Metaphors and Analogies]** • "Crane.... A person is a great example of a machine we are biologicly (sic) formed" **[from interview]**
Relations	**Relations** • "If we didn't have machiens (sic) Earth would not excised (sic) [exist] in space or would people for we are biologicle (sic) machines." **[from interview]**
Emotions-Values-Aesthetics • "Good, cool, robotic, no heart, no feeling, no brain, stupid, boring, no fun, buket (sic) of bolts, stupid looking, dump (sic) [dumb] car."	**Emotions-Values-Aesthetics**

(Table continued)

Table 10 (continued)

Metaphors/Analogies	**Metaphors/Analogies** • "We eat to charge we sleep to recharge We go to let are blader (sic) empty all the uneeded (sic) materials. We die when we have reached are peack (sic) and then the cycle starts with us again..." • **[do you see any similarities between our bodies and other machines...?]** "Well, sort of, with the crane because of, see, we have to pick up stuff and the crane works with the same idea because it has these strings as muscles and when, like, someone cranks it, it has all the pulleys and then it brings it up." **[from interview]**
Stories, Fantasy	**Stories, Fantasy**

TABLE 11

Categories of Student Discourse: Examples From a Pulley Activity (ST = student teacher).

SCHOOL KNOWLEDGE ("CORRECT ANSWERS")	
Lori	I finished mine. My answer is [reading from what she had just written]: "The ski lift that we built is a machine because of the wheels and the way (???) pulled the string. If you didn't have the wheels [pulleys] (???) wouldn't carry the chairs properly"
ST	**Okay, Mike?**
Mike	Oh, mine? [reading from what he had just written]: "You have two pulleys and two people pulling... chairs on the string. You pull the rope...." When the... the rope's on the pulley... you pull the rope, then it moves... the string, (???) chairs....
SENSE-MAKING	
ST	**... You guys have to write up your information for the clothesline activities first.**
Nathaniel	Well, we didn't exactly make it work.
ST	**Then you'd better help... get it to work.**
Nathaniel	It's the chairs.
Tim	She moved them too close together
	....
Lori	Let's take the string out, 'cause it's (???)... it needs to be right here.
Mike	[referring to a plastic pail] I know, there's a force, a G-force. When you're on, like, a roller coaster, and you go around....