DOCUMENT RESUME

ED 351 130 PS 020 868

AUTHOR	Brandes, Aaron
TITLE	Children's Understanding of Machines.
PUB DATE	21 Apr 92
NOTE	33p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Francisco, CA, April 20-24, 1992).
PUB TYPE	Reports - Research/Technical (143) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	Age Differences; *Childhood Attitudes; *Concept Formation; Definitions; Elementary Education; *Elementary School Students; *Knowledge Level; *Mechanical Skills
IDENTIFIERS	*Machines

ABSTRACT

This study, which examined children's understanding of machines, focused on how children decide which objects are machines and which are not, and how they group machines as similar or different. Brainstorming sessions involving two groups of four kindergarten children and one class each from the second, fourth, and fifth grade, were conducted. Interviews with 13 children from the same grade levels were also conducted. All subjects attended an inner city public school. Results indicated that, although children differed in the ways they decided which things were machines, a number of criteria were frequently used by children in making their decisions. These criteria included controls, power sources, autonomy, motors, functionality or utility, and complexity. Younger children were more likely than older children to focus on external properties, use a single criterion for determining if something was a machine, and make judgments inconsistent with previous ones. Older children demonstrated a greater sense of mechanical understanding than did younger children; were more likely to apply multiple criteria for determining if something was a machine; and were more sensitive to conflicts between criteria, than were younger children. Two appendices provide copies of the protocols for group brainstorming and individual interviews. (MDM)

CHILDREN'S UNDERSTANDING OF MACHINES

Presented at AERA
April 21, 1992

Aaron Brandes

Epistemology and Learning Group
Media Laboratory
Massachusetts Institute of Technology
Room E15-317
20 Ames Street
Cambridge, Massachusetts 02139

Abstract: Structured interviews were used to explore elementary school children's concepts of what makes something a machine, and how machines work. Although children differed as to which things are machines, a number of criteria frequently used by children to determine "machineness" were found: controls, power sources, autonomy, motors, functionality (utility) and complexity. Children differed in the number and consistency with which they invoked these criteria. Attention was paid to the developing richness of children's concept of machine with increasing age.

1 INTRODUCTION

Machines are a significant part of the modern world. Understanding children's understanding of machines is important for educators preparing children for lives in a world in which machines play an increasingly important role. This understanding may help in creating environments that will enable children to develop powerful, positive and appropriate relationships with machines.

Cognitive and developmental psychologists have given us much insight into children's understanding of the physical world. Studying children's understanding of machines may help extend our knowledge of children's ideas in other domains, such as causality and agency. For example, children often invoke intentionality in explaining the behavior of robots, natural phenomena and people.

In this study, a series of individual and group interviews with elementary school children was conducted. Because we are interested in the texture of children's thinking about machines extensive quotations from interview transcripts are presented.

2 GOALS OF THE RESEARCH

We[1] began this research with some basic questions about children's understanding of machines, trying to document the extension and *development* of children's concept of machine.

---

[1]This research is a collaboration between Edith Ackermann and Aaron Brandes.

Beyond knowing which objects children considered as machines, we were interested in *how* they made their decisions. Did they have any criteria for what is a machine, and what is not, which they could make explicit? We wanted to explore children's *ontology* of machines. We explored how children group machines, and which machines they see as similar.

To what extent do children look at machines as black boxes? How much of a sense of mechanism do they associate with machines? We had a particular interest in cybernetic mechanisms and feedback, but did not explore it in depth in this research, in part because one of the overriding goals of this exploration was to develop a sense of what is salient about machines to children. For this reason we wanted to design questions and formats which would be evocative, so that children's ideas would emerge, rather than be forced into a mold.

3 RESEARCH PROCEDURE AND INSTRUMENTS

We began by developing a protocol for group brainstorming sessions[2]. The purpose of the brainstorming sessions was to give us quick access to many children's ideas about machines. The sessions also provided feedback as to which of our questions worked well, and which did not and which ideas about machines resonated strongly, and which appealed to only a few children.

Brainstorming sessions were conducted with one class each from the second, fourth and fifth grade at an inner city public school in the Boston area. Since it seemed impractical to work with an entire kindergarten class, we worked with two groups of four kindergarten children. In all sessions children were encouraged to share their ideas, and told that many children (and adults) have varying ideas about machines. All sessions were audiotaped and transcribed.

---

[2]See Appendix 1.

It should be noted that in both the group and individual situations, the protocols were used as a guideline, not a rigid format. Additional questions were frequently asked in order to get children to sharpen their distinctions and arguments (for example when some second graders argued that a toy robot was not human because it was smaller than a person, we asked how it differed from a fish). Questions were sometimes dropped (e.g. when a child who consistently identified as machines the objects which used electricity said after several series "You know what I'm going to say.") or asked in a more natural order (e.g. if a child spontaneously mentioned remote control cars, a question about remote control might then be asked). Interviews typically lasted 20 minutes, but were longer or shorter based on the interest and energy of the interviewee. Only one child (a kindergartner) terminated the interview before we reached a state of completion.

The individual interviews were conducted with 13 children (7 boys and 6 girls) in kindergarten and grades 2, 4, and 5. Interviews were conducted in a room at the school. Interviews were led by one of the researchers, but when both were present, the other researcher frequently added clarifying questions or examples. [3]

4 OBSERVATIONS: CHILDREN'S SENSE OF MACHINES

4.1 INTRODUCTION

Some expected differences along age grounds were observed. When asked for a definition of machine, the younger children (kindergarten and second grade) often gave examples. The older children were capable of formulating their own definitions (and in one case, looking in the dictionary for a definition). The kindergartners were much more suggestible/responsive to what other children said. They were also more likely to go off on tangents. Surprisingly however, one kindergarten group and the second grade class, both talked about machines which made things (including other machines). Children of all ages talked about robots. The younger

[3]Cora Lee, who transcribed most of the interviews, was usually present.

children talked a lot about things they would like robots to do for them.

4.2 CHILDREN'S CRITERIA FOR "MACHINESS"

What sort of objects do children think of as machines? We found that children varied in their perceptions. More interestingly, we found that children differed in the types of justifications they used, and the consistency of their reasoning. In this section we present data from children's responses to the questions asking which elements in a collection are machines, and to the requests for a definition of the word *machine*. The data is organized by various features the children found salient about machines. It attempts to give the flavor of the interactions between the children and the researchers. It is organized to show the development of the concepts with age.

Note that in all the interview excerpts, the interviewer's words are in the left column, and the interviewee's are in the right. An ellipsis (...) or a square bracket ([]) within a line represents a pause or hesitation by the speaker. A line consisting entirely of an ellipsis means that part of the interview has been omitted. All names used for the children are fictitious.

Controls

Controls, such as switches and dials, were particularly salient to kindergartners and second graders. Here are some excerpts from the interview with Alicia, a kindergartner.

Ok, do you know how a machine works?	
	You have to turn a control on the thing.
You turn on a control. So what makes it go?	
	The thing that you turn on.

This focus on switches permeates the interview. It is possible that this aspect was triggered by the interchange above. In any case it remains persistent.

Well, I'm going to ask you about some different things. And you can tell me whether they are machines, ok? So, what about scissors?

No.

No. Why aren't they machines?

They don't have nothing to turn on.

Later in the interview we can see that having a switch is seen as a clear criterion for a machine.

How could you tell if something's a machine?

Cause it has a switch.

Towards the end of the interview Alicia becomes a bit tired and silly. The switch theme persists.

And a headband is a machine.

It is? Why is a headband a machine?

Cause you have switches on to put on your head.I didn't know...There's a switch to go, when you put your head down, it goes right on your head.

These interactions with Alicia illustrate controls as a salient feature for machines. It also exemplifies how the youngest children interviewed focussed repeatedly on a single criterion for determining whether something is a machine.

Janie is a second grade child who used controls as one of her criteria. At first she accepts all objects queried as machines. Hence the following probe:

How about this book binder, is this a machine?

No.

How do you know?	
	...
What would it have to have to be a machine?	
	Controls.

As we will see later, Janie has other criteria besides controls. Here is part of an interesting exploration of controls as a criterion:

You know what a motorcycle is, right?	
	[nods her head]
Is that a machine?	
	Yes.
... How do you know that one?	
	It moves.
It moves. What about a bicycle?	
	No.
Does a bicycle move?	
	Yes.
So what's the difference?	
	The motorcycle has controls.
Like what kind of controls?	
	Electric.
Electric controls. Do you know where they are, the controls on a motorcycle?	
	[nods her head no]

Notice that Janie introduced a new criterion (it moves) to justify the motorcycle being a machine. She later used the control criterion again, although the discussion as to what the controls are showed considerable lack of clarity. This appeared to be in part due to her lack of detailed familiarity with motorcycles. Her use of a multiplicity of criteria was a typical difference between the kindergartners and the older children.

Power Source

The use of a power source was a significant criterion for many children. Although Muhammed did not mention it explicitly in either defining machines, or saying how they worked, electricity and gasoline figured strongly in his conversation.

So, I have some questions about some things and I'm going to ask you whether you think if they're machines or not. O.K., what about scissors, regular scissors. Are they machines?

No.

Why isn't it a machine?

Cause it don't got electricity.

O.k. No electricity. Alright, what about a lawn mower?

lawn mower, yes.

Yes, does it have electricity, though?

Yes.

What about if it uses gasoline?

It'll still mow it, it'll still move.

Yes, it'll still work. So it'll still be a machine?

...

You know about the kind of lawn mower that you push?

Yes.

It doesn't have any--

Electricity.

So, is that a machine?

No.

O.k., what about a pencil sharpener. You know the kind that you use with a crank?

Yes, that's not a machine.

It's not a machine. Why not?

It don't run by electricity.

This focus on electricity lead to one very non-adult classification:

Yes, ok. How about a light? Is a light a machine?

Yes.

Yes...

Cause it runs by electricity.

Note that gasoline was also a relevant power source:

How about anything that goes with gasoline?

A machine.

This concentration on a power source lead him to over-attribute things to the toy robot:

It's a machine, ok. We're going to look at this robot. What about this robot?

A machine. It's got a wind-up.

It's got a wind-up. So, this is a machine?

Yes, cause it can walk.

Ok. But does the robot have electricity?

No.

No. But it is a machine?

Yes. It's got gasoline to move it.

It has gasoline.

Yes.

You think there's gasoline in there?

Yes.

Yes. Where does it go?

Here Muhammed points to the toy robot. This is a case where the strong application of a criterion appears to override a realistic assessment of the situation. (Muhammed is aware of the winder, he has not seen gasoline introduced into the robot.)

Autonomy

For some children it is important that the machine do at least a significant share of the work. Reggie (kindergarten):

Like, are scissors machines?

No.

No? Why not?

Because you have to put your hand in and you have to do it yourself.

...

Very good. Now what about a bicycle?

No, that's not a machine.

That's not a machine? Why?

	You have to pedal yourself.

Here's a similar example from Robin (a fourth grader):

scissors. Do you think that's a machine?	
	No.
No? Why not?	
	Cause you have to work with your hands.

Motor

The younger children frequently focussed on the most visible aspects of a machine - switches, plugs, electricity and gasoline. However one second grader very explicitly made motors a key criterion: Raquel

You try to tell me what is a machine. Like if you had to explain to someone what is a machine, how would you tell them?	
	It's something that has a motor.
Yes.	
	And it...
Yes? Some other ideas?	
	No.
...	
Like a car, is it a machine?	
	A washing machine.
A washing machine, yes. What about a car?	
	It has a motor.
Yes. What about a washing machine?	
	It has a motor, too.

Functionality

This includes the lines of argument that appeal to the object performing a useful function, or helping people. This was often a secondary consideration. Children tended to consider non-functional thing which used motors or power to be machines (though further exploration is merited). Children varied as to whether a functional things which did not use power was a machine. For some children the conflict between functionality and another criterion (such as having a motor) resulted in confusion Raquel (quoted just above) :

Ok. And what does a machine do, normally. Let's say what does it do?

It helps us do things.

Exactly, it helps us do things. Good.

She then proceeded to use it as a explanatory principle, although while giving a definition, she could only think of a motor as required. Like, do think scissors is a machine?

Yes.

Yes, why?

Because it helps you cut things.

Because it helps you cut things, great. And a lawn mower?

That's a machine. It helps you cut things, too.

It helps you cut things, too. Now, what is difference between the scissors and the lawn mower?

Scissors cut paper and the lawn mower cuts grass.

The lawn mower cuts grass, exactly. And does the scissors have a motor?

No.

Here we find a conflict between two criteria having a motor, and being useful. Raquel shows a lot of confusion when asked about the bicycle.

Now, let's see. What about a bicycle?

...

What would you say. A guess, just a guess.

It isn't a machine?

We don't know. What would you rather say? Is it one or not?

Would you say it is a machine or not?	Not really.
Why not?	I don't know.
You don't know. Does it help us do something?	Yes.
What?	Go places.
Go places. Does it have a motor?	No.
No?	Well, you have to make the motor run with your feet.
Exactly. When you pedal, right? You get it going. So, what do you think?	It's a machine.

This exchange is interesting, because Raquel show some characteristics of the younger children, and some typical of the older children. Like the younger children, she seems easily influenced by recent statements (e.g. bringing in the helpfulness criterion after it surfaced in answer to another problem). At the same time she makes use of multiple criteria, and also finds it difficult to make a classification when faced with a conflict. The kindergartners, in contrast, usually stuck to one criterion, and did not seem aware of their contradictions, or have difficulty in deciding if something was a machine.

In contrast, Andrew (grade 4) keeps a clear principled difference between the scissors and the lawn mower:

Like scissors, like regular scissors, are they machines?	No.
No, how come it's not a machine?	Because it doesn't have an engine.
What about a lawn mower.	Yes.
Yes, because..	Because it can move around different places. It cuts up grass.
But scissors cut up paper.	Yes, but it doesn't have a motor.

So, lawn mowers with motors are machines. But have you ever seen the kind of lawn mower that you push, the old-fashion kind?	
	Yes.
Is that a machine?	No.

Complexity

The older children often referred to parts of a machine such as gears. When faced with borderline cases (complex objects without motors) they sometimes said something about it being "like a machine". Here is Anthony (grade 5) explaining which dolls are machines:

	A doll.
A doll, ok. So a doll would be a machine, too. Are all dolls machines?	
	No.
No? How can you tell which ones are machines?	
	The arms move, when something's broken you can screwdriver and open and see its hard parts are broken or needs new parts

Summary: The Development of the Machine Concept

Extensive excerpting was used to give a sense of the children's responses in the individual interview situation. A number of ideas have been distributed throughout these excerpts. I will bring them together briefly here. Children cite a number of criteria in defining or explaining what makes something a machine. The principle criteria are: controls, power source, autonomy, motors, functionality and complexity. Although the younger and older children frequently cited similar criteria, there were many differences in their responses. The younger children were more likely to focus on a single criterion.

When they used multiple criteria, they did not seem concerned with possible contradictions. They were less likely to sound doubtful in potentially ambiguous cases. In general they focussed more on the exterior, functional aspects of things (e.g. switches, plugs, batteries), whereas the older children exhibited more of a sense of mechanism (e.g. gears, wires, motors). This was also seen clearly in the increased sophistication of the explanations they gave for how a remote control works, or how a washing machine can perform a number of different functions sequentially (see section 4.3). One could say that the older children had a richer sense of "machineness." They were familiar with more machines, and had more of a sense of how they worked.

4.3 DIFFICULT MECHANISMS - TWO EXAMPLES

The children rarely referred to mechanisms in explaining why something was or was not a machine. In fact they frequently referred to externally visible features such as switches or behavior. We asked them to explain how two difficult mechanisms worked: remote control, and washing machines. Part of our interest in these examples is that is something special about the behavior of each for which an explanation can be requested. In the case of the remote control, a result is effected without any visible physical connection. This eliminates classes of explanatory elements like motors, which can be used by children to explain machines as different as cars and electric clocks. What is particularly interesting about the washing machine is that it is "mechanical" rather than "electronic" by nature, yet it performs a number of tasks sequentially.

In each case we found a range of explanations. These ranged from avoiding the question to an explanation which captured the basic principle involved. Although older children generally had stronger explanations, this was not uniformly true. Excerpts from the protocols will again be used to illustrate typical responses.

4.3.1 Remote Control

Remote control cars were mentioned spontaneously by a number of children (mostly boys). Almost all children questioned were familiar with television remote controls. Only two of the children were able to give somewhat plausible explanations of how they worked. Many children had no idea how it worked. Here are a range of responses :

Reggie (kindergarten) has no idea how remote control works:

I have a remote control car but it got broke.

E: It got broken? How does that work?

If I had a remote to drive it.

A: How does the car know to go?

I don't know.

A: So if you turn the dial--you don't know?

I don't know.

Muhammed (a second grader) struggles to explain how it works:

Do you have machines in your house?

[ ] We got a remote control car.

Yes, that's pretty interesting. How does that work, a remote control car?

It needs batteries and it needs--and it got a remote control.

And how does a remote control work?

By handle.

So we have a little handle and you turn things.

And you press buttons [ ].

And how does that tell the car what to do?

...By using it. Like...

Is there a remote control connected to the car?

Some are, some aren't.

How does it work if it's not connected.Do you know?

By antenna. By the antenna.

By the antenna. What does the antenna do?

When you press the button,press it [ ] and the stuff will go to it and it'll start moving.

Wait, it will go to where?

Wherever you move the things that you move. It'll go where you want it to go.

The car will go the way you want it to go?

Yes.

O.k. But what I'm saying, you push a button and then what happens?

It'll just move.

O.k. But before you said it has something to do with the antenna. I didn't understand that.

Muhammed invokes all the elements he is familiar with: power (batteries), controls (handles), and repeats the process needed to produce the desired action. He even focuses on the importance of the antenna. However he lacks the crucial concepts needed to produce the car's motion without a physical connection.

A fifth grader introduces remote control early on (Anthony):

How does a machine work?

Batteries, remote control, or just nothing.

His explanation of how it works is similar in character to Muhammed's.

So, do you know how that works, remote control?

Remote control needs batteries or has a line.

It has what?

It has a black, and the remote controls is hooked on to the back and it goes right to the car. Instead it moves by itself, you have to go with it.

Some remotes don't have any wires, right? So, how does it work? I know you turn the little dials and it makes the car turn but how does it tell the car? If there are no wires.

By the control. Not when you move the whole thing, you have to move, like, the buttons. If you want to go that way, you press that way.

Right, when you push the button, how does the car know if you pushed the button.

I don't know.

Anthony speaks at greater length than Muhammed, but the elements of his explanation are quite similar. Robin (fourth grade) gives an explanation that brings in more of a sense of the mechanism. He is explaining how a robot at the Science Museum works:

It worked by remote control.

Remote control. What makes remote controls work?

Batteries.

Batteries, are the batteries in the remote control or the thing that goes?
Or both.

Both.

They both have batteries.

But the robot gots wires in the back and the remote control got batteries.

So, you press the remote control and the robot does something?

Yes.

What makes the robot know what to do?

By the person pressing the buttons.

But how does it, when you press the button, how does the robot know you pressed the button?

Cause it got the signals.

So, the signal went from the remote control to the robot. And what kind of signal, do you know?

No.

Robin brings in the additional concept of *signal* . However she does not have a clear idea of how this might work. Another girl, Shamia (fifth grade), gives the most detailed account:

You know what I mean, a remote control kind of thing?

Yes, a VCR or a TV, a stereo, or maybe a light can be remote, or...

You ever see a remote control car.

Oh, yes. A remote control car, truck.

And how does remote control work?

It works by buttons. Or batteries.

But it's different, like when you have--are there wires that make it work?

Yes.

When you have the remote control and you're doing the TV, there aren't any wires that go between the remote control and the TV, right.

But the wire is in the remote control, or in the VCR and they connect to each other and they do work.

Each of them has wires inside, so how does the stuff go from the wire in the remote control to wires in the VCR?

A sensor in front of the remote control, it sends to the VCR and that means to make it play when you press play.

But what does it do to the...

When you press a button the sensor on the remote control, when you press play it tells the remote control that it wants the VCR to play.

So, there's a sensor on it?

Yes, it's on the remote control or on the VCR.

How does the sensor communicate o other sensor?

It communicates to the other sensor on the VCR and that shows it to play when you press play.

But it goes through the air.

Yes, by the signal.

Shamia's explanation begins like the others, referring to the batteries. However, she has an additional mechanism (the sensor) which she is able to bring into her explanation. She is not, however, clear as to the nature of the signal.

The difficult question of how a remote control works elicited a range of responses. (How well could most adults answer?) The responses increased in sophistication with age, but not uniformly. The simplest attempts at explanation referred to the visible physical components of the system. Other explanations were descriptions of the behaviors needed to operate the remote control. Only two children could bring in the idea of an invisible signal. Only one child mentioned sensors. It would be interesting to see to what extent children's with experience with LEGO/Logo sensors would influence their answers.

The older children also saw more clearly that there was something to be explained, even if they could not offer a clear explanation as to how the remote control worked. The younger children seemed to simply see remote control devices as another example of things which worked. As long as they can get the car to do what they want, they do not feel a need to understand how it works.

4.3.2 The Washing Machine

The washing machine is an example of a machine which does not simply perform a single function once action is initiated by the user. An electric pencil sharpener will keep sharpening until you remove the pencil. The toaster will pop the toast up when it is done, a more complex task (at which my toaster sometimes fails, despite boasting of a "bread brain"). A car is complex, but not very autonomous - you must steer it and control it via the gas and brake pedals. The washing machine performs a series of functions, yet you initiate the behavior only once. As was the case with the remote control, we found a range of responses as to how this was possible. Once again, the youngest children seemed less to think there was something which needed explanation.

One kindergartner (Alicia) was clearly familiar with washing machines. Yet she did not seem to understand the question at first, and then changed the subject.

What does a washing machine do?

It the thing that you wash clothes.

Yes, you wash clothes in it.

You put some stuff in it that makes the clothes clean.

Yes, that's called detergent.

Detergent stuff.

Yes. And then there's a button on it right?

No.

No button?

You have to--there's a thing that you put money in.

Oh, you put money in it.

It's like this (she demonstrates). And you put the money in that.

You're right. At the laundromat. Did you ever, when you have a washing machine, it does different kinds of things, so you ever watch it? First the water comes in and then it es swoosh, swoosh, swoosh. And then, later on it spins around. You never listen to it?

Yes, I have one at my mom's and my grandmom's.

So, how is it that you have to tell the washing machine all the different things that you have to do?

The teen-age mutant is a robot.

Another kindergartner (R.ggie) gives a more detailed explanation of what the washing machine does. He notes that the name gives away the fact that it is a machine.

Well, tell me something. A washing machine is a machine, right?

Yes, cause it got a washing *machine*.

What do you have to do to get it to work?

You have to turn something and [ ]something and it washes, makes the-- pour bleach and stuff in it at the end. It washes it.

Do you have to tell it a bit more than push on a button for it to wash things for you?

No.

No?

You just have to turn it and it comes on, and then...my dryer you just have to turn something, then press the button, then it dries.

What does it do when you turn? Do you know?

It makes the water for you...

Yes.

And put your clothes in there and put Tide and bleach in there and stuff, and it does...

...does it for you.

But when you dry, you exactly put the clothes in there cause now you have wash [ ] then you turn it and press the button and then it goes on.

Does it all by itself? Tell me something, is a washing machine smart?

It's a robot. So, all I know is it's a robot...

Can you say it knows how to wash the clothes?

It knows how to wash clothes.

It knows how to wash clothes.

The robot is used here as an explanatory principle. However this seems to be prompted by the interviewers question as to whether or not the washing machine is smart. This is an example of the suggestibility of the youngest children we interviewed.

Anthony (grade 5) has some idea of what is inside a washing machine, but no idea of how it can change cycles.

Do you have machines at your house that do things without you making it do them. Or when you're not there, if they still are working?

A washing machine.

Yes.

You just put the clothes in and press the button and it'll just wash and then when you're done just put them in the bag. Or you can hang them out or you can bring them to the laundromat to dry them.

Yes, so the washing machine, that's an interesting one. Cause the washing machine does a lot of different things, right? When you first put in the clothes...

It wash.

...the water comes in, right.

Yes, they wash and they spin.

And it spins, right.

And they rinse.

So, how is it that the washing machine can do all those different things?

It probably does have a motor. A lot of wires. I don't know if it has a battery.

But does it do different things? Some machines, like when you plug them in and you turn them on do only one kind of thing.

Yes.

Like the pencil sharpener, it only sharpens the pencil. It doesn't do something else, right? So, how does the washing machine go from doing the wash part to doing the spin part? What do you think happens?

You have to turn it--no. It goes, when it's done washing, it goes to rinse then it'll stop and you'll open it and see. And then add the bleach or washing powder and see then when you're done with all that you put the lid back down and it'll start to spin.

But do you have to do something to make it spin, or will it do it by itself?

It do it by itself.

How does it decide to do that?

I don't know.

But it's more complicated than some other machines, though.

Yes.

One second grader (Janie) noticed a connection between the movement of the dial, and the actions of the washing machine. Despite being asked leading questions she did not make a connection with other machines she knew. This was a rather lengthy interchange, in which she discussed the cycles in detail, so it has been significantly edited. As before, a line consisting entirely of ellipses (...) indicates that material has been omitted.

A: So, when a washing machine goes, it does a lot of different things. What kind of things does it do?

It washes, it pulls water up.

A: Yes, it makes water go.

Bubbles.

E: Yes, the soap.
A: In the end it goes, brrr. It spins really fast, right?

Yes.

A: It does all those different things, do you have to tell it do all those different things?

No.

A: So how does it do that?

Sometimes when you're in the store, when you don't have a washing machine, you have to put money in it.

...

The thing that you do like that is attached to the machine. Go like that.

A: What happens to the dial, does the dial do something when the machine is going? What were you saying about the dial. I didn't understand. It sounded interesting, though.
E: You put the dial like this and then it makes it turn.

Yes.

E: How is it possible that a machine sort of does not only one thing because if you turn the dial like this, it makes it turn, right? Do you some idea of why, then suddenly it knows when to stop and the water goes in. It does all these things in the right order, like it doesn't get crazy?

I don't know.

E: You don't know?

I just see my grandmother wash the clothes. And I see how she turns the thing.

A: Did you ever notice, you should watch sometime, when you first turn the dial, then if you watch the dial, it actually turns while the machine is going.

First comes the water.

A: Yes.

Then comes the bubbles. Then take off all the water that has the clothes, and then it's going to go, zzzz. Then it spins.

E: Do you think it has a computer in it, like a program or not?

No.

...

A: ... I'll tell you one other thing that is similar. Did you ever see a timer, where you turn it. It has a dial and you turn it and it goes tick, tick, tick? And then in the end it goes, ding. Ever see that?

I have one.

A: Is that a machine?

Yes.

A: How do you know that's a machine.

It has a button.

A: Anyway, I think there are ways in which the timer and the washing machine are similar.

One second grader (Micheal) however, spontaneously brought in the programming concept. (The following exchange is reconstructed from memory.)

How does a washing machine work?

It has a motor.

But how does it do different things, like adding water and spinning?

It's programmed.

What do you mean.

It's programmed like a computer.

One other student (Shamia, a fifth grader) also saw the washing machine as programmed.

How about, I'm going to ask you about a particular machine, the washing machine. You ever watch a washing machine?	
	[nods her head]
A washing machine, you know, has different cycles, right? The water comes in, and then what happens?	
	It washes the clothes.
So, it like sloshes around.	
	Yes.
And then it spins really fast, right?	
	Yes.
So, how does it do all those different things?	
	By wires and gears and batteries. Or someone programmed it to do it.
So, you think it's programmed to do different kinds of things?	
	Yes.
Do you have to program it or someone programs it already?	
	Somebody else programmed it. The maker probably programmed it.
Does it do different programs or just one program?	
	It does different programs.
It has on the dial different ways you can set it, right?	
	Yes.
Sometimes it says delicate, or it says regular. Are those different programs?	
	Yes.

Summary: Difficult Mechanisms

In these excerpts, children are seen struggling with a difficult question. Some fail to see the difficulty. Others can only repeatedly describe the phenomena. Sometimes the children notice a physical feature which is relevant (the antenna in the case of the remote control, the dial in the case of the washing machine), yet the attendant principle is unknown to them, or does not seem relevant.

Yet in each case, a couple of them are to find something from their experience (sensors, programming) which they can relate to the phenomena in question. Thus experience with technology can broaden their ability to understand the world. Of course it it possible to go to greater levels of detail, and see how the programming of a washing machine and the programming of a computer differ. If an explanatory principle is used too widely, it may become vacuous (as I suspect was the case when the washing machine was likened to a robot).

5 DISCUSSION AND CONCLUSION

5.1 PROTOCOLS

Our experience with the brainstorming sessions led us to make some changes in our interview protocol. We dropped the question "What kind of groupings can you make of machines?" This question proved somewhat difficult for some younger children, and tended to produce only functional groupings (entertainment machines, transportation machines) by the older children. We also dropped the questions about which machines are similar (another attempt to get at the same thing). The most interesting comments children made on similarities and differences between machines was between machines with similar function, but different construction or mode of use. We therefore added a series of questions in which we asked which of a group of such objects (e.g. scissors, power lawn mower, push lawn mower) were machines[4].

5.2 EMPOWERMENT AND DISEMPOWERMENT

In reviewing the interviews, one thing which struck me was the way in which modern machines are simultaneously empowering and

[4]See Appendix 2.

disempowering. Children today have the ability to access and control machines which are powerful in a variety of ways (e.g. computers, VCRs, remote control cars). I believe that 100 years ago such near "state of the art" machines were not available to children. Thus on a practical or functional level, children are empowered. At the same time these machines are difficult to understand on a conceptual level, and have few visible mechanisms. In this way they are disempowering. It should be noted that these observations hold in part for adults as well. These machines cannot be easily repaired at home. In fact for much modern equipment, the debugging metaphor is more relevant than repair. I am interested in pursuing whether there has indeed been a significant shift in both children's and adult's relationship to machines over the last 100 years.

5.3 DIRECTIONS FOR FUTURE RESEARCH

This work could be expanded by working with a larger population of students. The current study involved about 80 children in the group sessions, as well as individual sessions with 13 children. Further exploration could involve working with more children over a wider age range. The results of this study could be used to refine and extend the investigative procedure. It would be interesting to observe interactions between students, who may have different criteria for deciding what is a machine. Conducting multiple interviews with children would be valuable both to test the stability of the ideas they put forth, and to explore their understanding in greater depth.

Further research in children's concepts of how machines work, and the extent to which children are curious about how machines work would also be valuable. In making such explorations I think it would be valuable both to observe children playing with and analyzing machines, as well as giving children opportunities to build their own machines. Making observations in a naturally situated context would also be valuable.

Most children considered the wind up toy robot to be a machine. Yet it did not in fact meet the criteria of requiring power or a motor which were important to many of these children. It would be interesting to explore in more depth children's ideas of how it worked, as well as the extent to which it "stood in" for a real robot.

The affective side of children's relationships to machines is also of interest. The younger children mentioned many machines that were oriented to fulfilling their desires e.g. machines to make candy or do their homework. What kinds of machines would children like to have? What machines do they feel intimidated by? What kind of experience most influences children's relationship to machines?

This study primarily focused on age as a variable factor between children. Although we were attentive to the possibility of gender differences (and therefore interviewed a even balance of girls and boys at each age level), much can be done to explore this dimension. Sensitivity to cultural, class, ethnic and individual differences is also important. A case study approach could incorporate insights from a broader view of the particular chiidren involved.

5.4 CONCLUSION

Throughout this exploratory study, we discovered that children's ideas about machines form a rich field for observations about human development. This report gives the texture, as well as some analysis of the results. Children use a number of criteria, including controls, power source, autonomy, motor, functionality and complexity in deciding whether an object is a machine. Younger children tended to focus on more external properties, and make use of a *single criterion.* Their judgements were often *inconsistent* with previous ones. Older children's discussion of whether things were machines reflected greater experience with machines, and a greater sense of mechanism. They were more likely to apply *multiple criteria* than younger children, and more sensitive to *conflicts* between criteria.

Two prototypic classes of machines for many children appear to be objects powered by motors and electronic devices. Complex mechanical objects such as a wind up watch or a bicycle were thought by many children not to be machines. Growing up in a technologically advanced age, children interact with machines which are more powerful, and more mysterious than those most familiar to their grandparents.

The realm of machines thus provides a rich ground for educators to foster children's growing appreciation and understanding of the world, and for developmental and cognitive psychologists to explore and understand this growth process.

Acknowledgements

I would like to thank Karen Heywood, Barbara Boisvert, Leilani Linden and Maria Harvey of the Agassiz School for the generous use of their classroom time. Thanks to Cora Lee, who transcribed the bulk of the interviews. This research is a collaboration with Edith Ackermann who has been a valuable source of ideas and encouragement. Thanks to David Chen and Uri Wilensky for their feedback on this paper. All of this would not have been possible without the participation of the children, who shared their ideas about machines and how they work.

This work has been supported financially by:

The National Science Foundation (Grant MDR 8751190)
The MacArthur Foundation (Grant #874304)
The LEGO Systems A/S
Nintendo

Appendix 1: Group Brainstorming Protocol

Questions for exploring the notion of machine in brainstorming groups: (Questions were all presented verbally.)

What is a machine?
Can you give a definition like one in a dictionary, so that someone younger who didn't know what it was could understand?

What are examples of machines?

Is this a machine? Why or why not?: (Items marked with a * were physically present.)
scissors, *pencil sharpener, *toy robot, human being, baby, doll, doll that cries, ramp, rock

What kind of things make a machine work?
(Deliberately ambiguous question, designed to solicit ideas such as: components, mechanisms, power sources)

Take out the toy robot and ask questions about it. Wind it up and let it walk.
Is it a machine? How does it work? Why does it stop?

What kinds of groupings can you make of machines?
What machines are similar?

Given a pair of machines, say what they have in common, or what group they are both in.

How do machines differ in terms of how a person must interact with them to get them to work?
e.g. the robot you wind up and let it go, but the scissors you need control yourself.
car versus toaster

What do you need to make the washing machine work?

What machines work in your home when you are not there?

Appendix 2: Individual Interviews Protocol

Questions for exploring the notion of machine with individual children:

Objects listed with a * were physically present when questions about them were asked.

What is a machine?

[possible follow up to get more precision]

Can you give a definition like one in a dictionary, so that someone who didn't know what it was (perhaps younger) could understand?

How does a machine work? [deliberately open ended]

What are examples of machines? [if haven't gotten a good set yet]

What machines are in this room? [for children having trouble]

[to sharpen issues of what forms the machine concept]

Is this a machine? Why or why not:

a) scissors
   lawn mower (gasoline or electric)
   push lawn mower

b) skateboard
   bicycle, car, motorcycle
   scooter (foot powered)
   pedal powered airplanes [at science museum]

c) windup watch (if unfamiliar try grandfather clock wound weekly)
   *classroom clock with gears (moves only by hand)
   *classroom clock for showing time (hands only)
   *electric clock

d)electric pencil sharpener
   *rotary hand pencil sharpener
   *little pencil sharpener

e) bottle opener
   hand can opener
   electric can opener

f) machines like ones at science museum and airport with lots of gears etc. which move balls around, but are not functional .

What machines work in your home when you are not there?

Show the *toy robot
Ask "is it a machine"
Ask if child has seen a real robot - in person or on TV.
Ask what real robot did
Ask "is it a machine"
Demonstrate toy robot - wind up, let walk, let run down
Ask again if it is really a machine.
Ask why toy robot stops.
Explore what makes toy robot go
Does the toy robot know that it stops?
For robot and human:
why does it stop?
does it know that it stops?
[optional: Computer - Is it a machine? Does it think? Other???]

Remote operating/control

Can you think of machines that work when you are not at home?
Or machines that operate when you are not touching them?
Explore what makes them go on/off.

How does the washing machine work?
How does the washing machine do different things [water in, slosh water, spin etc.] without your telling it?

How does a remote control TV or car] work?