When a scientist does an experiment, does the scientist expect it to come out a certain way?

IF YES:

What do scientists think when their experiments come out the way they expected?

What do they think when their experiments come out differently from what they expected?

18. When would a scientist change his or her ideas? Why?

13. Have you ever heard the word "theory"?

IF YES: What is a theory?

Could you give an example of a theory?

Science Self-Image

Do you like science? How much?

Are you good at it?

What does that mean?

What abilities do you have that are important to be a scientist?

Are there any abilities you don't have you would need to be a good scientist?

Attitudes Toward Science and School-Science

Do you ever do science activities for fun?

Which ones?

If NO, ask about what they like which might be considered science. e.g. ask if they do nature activities—is that science?

Do you ever read science books or articles for fun?

Do you watch programs on TV about science for fun?

What was your best science experience?

Appendix B: Image of Science Interview Guideline

Name: Date:

Ask a warm up question, based on their personal information.

Ideas About Science

NOS[11] 1, 2, 3 (adapted)

1. What is science?
2. What is the goal of science?
3. What do you think scientists do?
   What are some other things that scientists do?

What kinds of things do scientists study?
What do you imagine scientists are like? What kind of people are they?
How do scientists compare to other people?

Ideas About Scientists:

Picture from Draw-A-Scientist Test
(Administered in advance)
Clarify gender. if needed
Clarify questions about picture e.g. what scientist does in work day.
Ask about any equip. scientist is using.
What other kinds of equipment do scientists use?
If more than 1 scientist in the picture: ask about the relationship between them.
If 1 scientist in the picture: I noticed that there is only 1 scientist in your picture.
Does your scientist work alone?
Do scientists usually work alone or in a group?
What are advantages of working alone?
What are advantages of working in a group?

Nature of Science/How does the scientist proceed:

NOS 4-20 selected
NOS 4 Do you think scientists ask questions?
What sorts of questions?
NOS 5 How do scientists answer their questions?
6. What is an experiment?
7. Do scientists do experiments? IF NO, skip next few questions.
8. Why do scientists do experiments? IF "to test ideas,"
THEN: How does the test tell the scientist something about the idea?

[11] NOS items are taken from the Nature of Science Interview protocol developed by Carey *et al.* (1989).

Is there anything else you would like me to know about you?
(You can use other side.)

Appendix A: General Background Questionnaire

Name: Birthday (day, month, year):

What is your favorite thing to do outside of school?

What is your favorite thing to do in school?

What do you want to be when you grow up? Why?

What things are you best at (outside of school)?

What things are you best at (in school)?

What's hard for you (outside of school)?

What's hard for you (in school)?

What kind of thing do you dislike doing?

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am grateful to all the children who shared their time, ideas and feelings with me. They helped me see what works and what makes sense, and to appreciate the challenges they face daily. I respect the work they do. The preparation of this paper was supported by the National Science Foundation (Grant # MDR 8751190), the LEGO Group, and Nintendo Inc., Japan. The ideas expressed here do not necessarily reflect the positions of the supporting agencies.

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> What skills of the children are tapped and strengthened by the science experience? The ability to memorize, to follow instructions, to generate questions, ideas or solutions The ability to work with their hands? Science activities should provide children with a range of ways to succeed, so that they can develop a realistic foundation for high self-esteem with regard to science.

The image of science concept can also be used to understand and help individual children. For example, open-ended exploratory science activities may not make sense to a child who conceives of science as a collection of facts to be learned. Helping the child broaden his or her understanding of science may help legitimize the activity. The activity may then help the child's construction of a deeper understanding of science. A child who may automatically "tune out" during a science class because he or she is self-identified as not being a "science kid" will benefit from experiences in which his or her abilities (e.g. to generate interesting questions or to make a measuring device) are valued.

6.2 Directions for future research

One direction of future research is to trace typical patterns of development of image of science over a wider age span. In looking for such patterns it will be important to pay attention to issues of gender, race, socioeconomic class, and personal experience with science and scientists. I am particularly interested in the dynamics of the interaction between the cognitive and affective aspects of children's images of science. I have suggested elsewhere (Brandes, 1994) how positive and negative feedback loops between these aspects may arise and either encourage or retard their growth. In my current work I attempt to explore in more depth the connection between the science learning experience offered in a classroom and its impact on children's construction of their image of science. Most importantly, I hope this research will lead to the generation of science learning environments and experiences that enrich the lives of children and enable them to build a better understanding of the world and a lifelong connection to science.

Acknowledgments

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potentially accessible and inviting to children. Such aspects include the role of questions in science and the role of designing and building measuring devices. On the affective side, we can explore whether such aspects can be used to engage children in science, and increase their self-perception of their science ability.

I would like to suggest a number of ways in which the concept "image of science" can provide a tool or language for analyzing the potential impact of a science learning experience. (This list is not intended to be exhaustive, but rather to highlight some of the considerations brought to the foreground by the focus on children's images of science.)

1. *Is the experience interesting, fun, and motivating? Is there a hook?*
   Although some children are favorably disposed to activities labeled as science (i.e. they assume that they will be good at it, and that it will be interesting), many others are immediately wary of activities they suspect to be science. Activities with great potential for science learning will not be effective for children who do not choose to fully engage with them. If the activity is fun, or taps into a deep interest or concern (e.g. helping animals) it is more likely to succeed.
2. *How does the experience portray science? As what kind of thing?*
   Engaging children's interest is however, not enough. Does the experience portray science as a collection of facts? Does it emphasize the use of particular methods? Portraying science as an enterprise directed towards understanding the world may lead to a deeper and more satisfying understanding of science. Facts and processes both have a role in such an understanding and are more motivated when given a context.
3. *What does the experience say about who can be a scientist?*
   For example, pictures of "great men of science" may reinforce stereotypes of scientists being male (or white). On a more subtle level, teachers' interactions can easily privilege the views or participation of particular children or groups of children. Furthermore, subject matter may have a differential appeal to children along the lines of gender or socioeconomic background.
4. *Does the activity reinforce the idea of science as static and known?*
   Even "hands-on" science explorations can reinforce the idea that doing science involves following recipes. If the only activities are ones in which the answers are already known and the problems anticipated, students will expect that answers lie with the authority of others.
5. *Does the activity offer insight into how new knowledge is generated?*
   Always concealing the messiness of the scientific process can make science unnecessarily mysterious, and reinforce the notion that it is an activity only for geniuses and experts. Experiments which require students to generate ways of organizing collecting or interpreting data (or to design measurement devices) would be a step in the right direction.
6. *Does the experience connect children's strengths and abilities to science?*

programs on TV etc., and need not have a uniform attitude towards or interest in all of them. Nevertheless, given these caveats, I feel these affective constructs can be useful. One distinction I would like to make is between science and school science. In my view it would be ideal if school science involved students in doing science explorations and developing an appreciation of what science is about.[9] One would then expect interest in science and school science to be highly correlated for the positive reason that the two were similar in essence. Unfortunately, I think the two are often highly correlated because children identify science as school science.

The children often made statements that indicated a clear overall stance towards science. One girl said she was not a "science kid," but thought other children were. One girl warned "You don't want to talk to me, because I hate science." Another girl indicated that she really liked science, but it wasn't her "top thing." This same girl also showed the discrimination in attitude the children were capable of. "Other children may like Sundial (an activity that is part of the Shadows curriculum), but I'm probably the only one that looks forward to it."

6. Conclusions

This paper has introduced the concept of *image of science*, and reported the results of three studies of elementary school children's images of science. The results indicate that although science can be exciting and magical to many elementary school children (particularly in the younger grades), their school science experience does not necessarily foster a greater understanding of the nature of science. Rather, it seems to promote an image of science as a school-like enterprise, in which hard work and increasingly advanced courses are the key to success.[10] Furthermore, it may reinforce the belief that science is the realm for an elite few (a belief also carried by popular media). By sixth grade, fewer students are excited by science or committed to learning about it. The image of sci ence concept suggests that these cognitive and affective developments may go hand in hand.

To put this research in a broader context, I will discuss ways in which the concept "image of science" can be a useful tool in the realm of science learning, and identify directions for future research.

6.1 Uses of Image of Science

The concept of a child's image of science provides a potential ground for integrating findings from the now separate research programs of children's ideas about the nature of science, and the role of affect in science learning. In exploring children's ideas about the nature of science, we can probe for aspects of science which are

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[9] For this reason I chose a research site offering children potentially rich science experiences.

[10] I do not intend to suggest that hard work is not required, but rather the sense of excitement is lost for many children. Children also see basketball as requiring a lot of practice and hard work. However in playing the game, they get some immediate reward.

5.3.3 Children's drawings

In some ways the sixth grader's drawings were similar to those of the younger children. Half of the pictures contained test tubes or beakers. The types of science most frequently portrayed were chemistry (8), biology (4) and medicine (4). Despite being in a classroom in which effort is made to involve boys and girls equally in science, only five (of 25) drawings were of female scientists, all of these were made by girls.

During the interview I sometimes elicited some personal significance of a drawing to a child. For example, one girl who is very interested in science drew a picture of her dad, who is a scientist (See Figure 4). Another girl drew a picture representing a growth study in which she was participating (although she drew a male scientist measuring himself). Only one child drew a picture that was an explicit self-representation—one boy portrayed himself as a doctor.

Although many pictures fit the stereotype of the lab scientist with glassware, some sixth-grade children also showed their awareness of such representations as stereotyped. One boy had his scientist saying "I've done it, at least I think I've done it, what am I making?" He intentionally made a dumb scientist, in contrast to the "Eureka" phenomenon. The latter was illustrated in a picture in which the scientist says "I've done it, I've almost computed the cloning system." One girl consciously went against the stereotype. She said she didn't want to create a "lab coat scientist," but rather a "new kind of scientist." Her picture included a stylishly dressed female scientist with chemicals and a caged animal (See Figure 5). She is working to make foods that are safe for the animals to eat.

Some children were reluctant to draw. These children tended to have negative attitudes towards science. Some children did produce pictures, given encouragement. Three children drew pictures that were avoidant of the task. For example one scientist was pictured taking a food break at 3:00. Another boy initially began to draw his scientist watching television, but then decided the scientist really should be working, so he gave him a screwdriver, and explained the evolution of the picture, saying that the scientist was about to take apart the television to figure out how it works. One boy (who was the only child not to participate in the interviews) drew an incomplete (head and part of torso) picture of what looked to me like a ninja.

5.3.4 Interest in and Attitude Towards Science

Through the interviews, questionnaires, and drawings I have developed a preliminary sense of the children's interests in and attitudes towards science. Science is, of course multidimensional. There are many disciplines within science, and many activities within a discipline. A marine biologist might not be fascinated by ants. A theoretical physicist may have little desire to design the apparatus needed to test her theory. Furthermore children experience a wide variety of science experiences: informal activities, class lectures, hands-on school activities, science learn to be a scientist if it just involved accidents. Then anyone could do it." Finally, he proposed a new model, in which the scientist starts with an idea, and then tries to work it out.

In summary—in comparison to younger children, these sixth graders showed a greater familiarity with the topics and activities of science. Some children showed awareness of science as an enterprise for answering questions about the world. They had some understanding of the logic of experimentation, and saw it as more purposive than many younger children. However, the process of generating new knowledge was still mysterious to them.

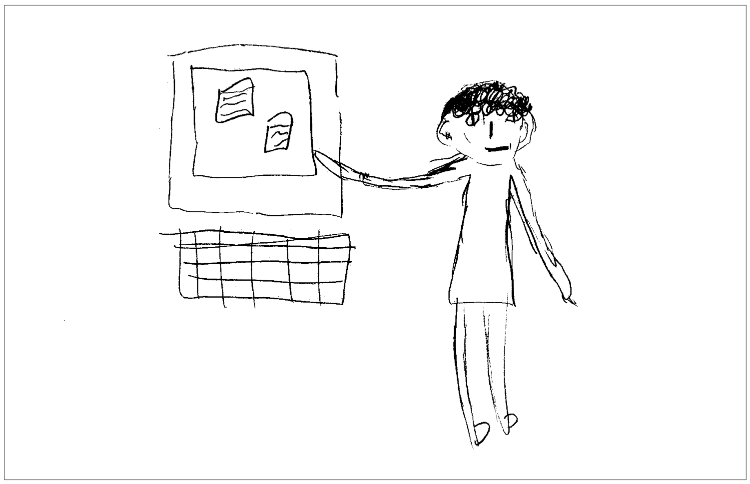

Figure 4: A sixth-grade girl's picture of a scientist, her dad.

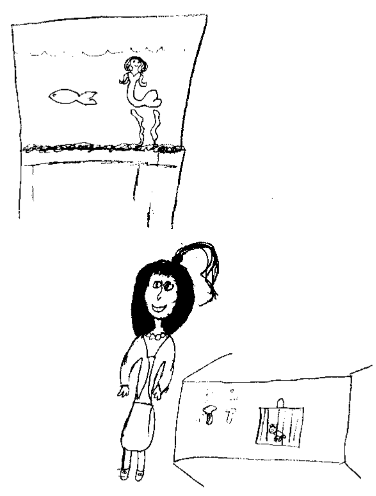

Figure 5: A sixth-grade girl's picture of a female scientist.

than many of the younger children although some of their ideas were in the "try something and see what happens" category prominent with younger children. They showed a bit more sophistication, such as "seeing the effects of radiation on people." One girl said she used to think that experiments were about mixing things when she was "a kid," but now she sees experiments as trying to answer questions. Another girl saw experiments as trying to "prove something." Several children mentioned ideas they had learned about experimentation including hypothesis, variables, and controls, although they didn't seem to have fully assimilated them. Most children had heard of the word theory. They primarily thought of it as being a guess or idea or thought about what might happen in a situation or why something would be true. A typical use of the word began "My theory is that...." Six children held that theories, once proven, become facts.[7] A number of children believed it could be meaningful to speak of a "true theory." One girl held it would be difficult to prove a theory because some people might not be convinced. No children held the idea of theory as a conceptual framework, which is one of the most sophisticated views probed for by Carey et al. (1989).

Half the children thought that scientists make predictions at least some of the time. Some saw that predictions could have a guiding role. They said that if things did not work out as expected, the scientist would try to do something differently. Others held the scientist would be upset, or know he or she didn't do it right. Two children said that if the prediction was correct the scientist would do more experiments or make another prediction—and the result would generate new research. Others saw that it would lead to knowledge—the scientist should write it down, and could use it to make further predictions. Generally, however, most of the children, even those most oriented toward science, found the process by which new information is generated to be quite mysterious. A conversation with one boy, Dan, illustrates this.

Dan is a bright sixth grader who wants to become a scientist so he can "expand human knowledge." He belongs to an astronomy club (with mostly adult members) and is grinding the lenses for his own telescope. When I asked him how he thought scientists discover new things, he spoke rather vaguely at first, about "trying new things."[8] He seemed dissatisfied with his explanation, however, until he remarked, "You know, scientists often discover things by accident." He gave the example of Goodyear, who discovered that rubber, accidentally spilled on an oven, became hard. When asked, Dan took his line of reasoning a step further, and stated that new discoveries are usually made by accident. "So," I asked him, "do you think that scientists go around trying to have accidents?" Together, we explored what science would be like if one had to make accidents to generate new findings, Dan suddenly shifted his view. "Really," he said "why would anyone want to go to school and

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[7] One boy holding this view explained that although we may speak of a "theory of gravity," gravity is really a fact, and the phrase was probably a holdover from earlier times.

[8] Some quotes given here are paraphrases based on notes immediately after the interview, during which the tape recorder failed.

teachers science sessions'. These observations give me an understanding of the children's current school science experience, as well as individual children's participation. I keep field notes, and audio-tape or videotape sessions involving the whole class.

In working with small groups, I am using methods I developed in my earlier work. First, the children brainstorm a list of topics they find interesting. Next, they brainstorm questions for some of these topics. Finally, the children and I explore some of the questions. Since many questions the children generate, such as "is there intelligent life in the universe (beyond the earth)" cannot be answered by classroom experiments, I have developed a method I call "the fantasy experiment." One child begins with a question, such as "what is the temperature on Mars?" The child then designs an experiment, with practical considerations reduced or eliminated. Thus "first I would build a space ship" is a legitimate first move. Other participants, including the researcher, can ask questions to get the experimenter to sharpen the experiment. If the final step proposed is "then I would get the temperature," someone might ask "how would you get the temperature?" Continued questioning would promote deeper thought about the role of measurement and constructing special equipment in scientific research. For example it would probably be necessary to build a special thermometer to accommodate the extreme temperatures on Mars. Through my participation in the questioning process, I will be modeling concern for aspects of doing science that I find to be important and accessible to the children.

5.3 Discussion

5.3.1 Sixth graders' ideas about science

Some sixth graders' ideas about what science is about were very similar to those of younger elementary school children. They mentioned numerous topics and activities. The topics fall under the same general categories that younger children mention: biology, earth and space science, chemistry and medicine. However, they mentioned more specialized topics such as genetics, and some referred to fields such as marine biology instead of just listing particular items such as sharks and whales. Experiments were by far the most commonly given activity. This represents a shift toward viewing science as an enterprise focused on increasing our understanding of the world. Six students explicitly referred to science being about explaining things, finding out how things work or react or finding out or using information. This aspect was also reflected in some children's view of the goal of science. Five children saw this goal as expanding knowledge or discovering things, four saw it as explaining how things work. The most popular answer (6 children) involved helping people, animals or the environment.

5.3.2 Experiments and the generation of knowledge

These sixth graders seemed to see experiments as a more central part of doing science

5.1.3 Methods

I have made use of drawings, questionnaires, clinical interviews, ethnographic observation, and small group work to explore and help develop the children's images of science. The first three methods were used over a one month period to develop an initial picture of each child's image of science.

Before the children gained much knowledge of my agenda (which may have influenced their responses), I gave them a questionnaire I developed to get a sense of their general interests and abilities in and out of school. (See Appendix A.)

The drawing task was the Draw-a-Scientist Test (Chambers, 1983) in which the children drew a scientist at work. In addition the children wrote on a separate paper the scientist's name, age, where they lived, what they are doing, and why they are doing it.

The study of children's attitude toward science is replete with instruments (Moore & Sutman, 1970) and severe critiques of those instruments (Munby, 1983). Instruments are criticized for mixing dimensions of study, not measuring what they claim to, and not being adequately tested. In studies which are primarily based on correlations between attributes as measured by such instruments, as well as by test scores and quantifiable behaviors, this is a serious weakness. However, in research that relies primarily on qualitative data, such instruments may provide an additional, quantitative "sketch" of the subject. Therefore, I decided to use the following two instruments to supplement data gathered through observations and interviews with the children.

I used the *Science Interest Scale* (Rennie and Parker, 1987) to measure interest in science. Children are asked to rate 16 specific items using a modified Likert-type scale in which they indicate whether they like the item content not at all, a little bit, a fair bit, or a lot. Rennie and Parker (1987) provide an analysis of issues concerning heterogeneity of populations and dimensionality of the instrument that should be useful in the data interpretation process.

The children's attitude towards school science was measured with the *Attitude Toward Science in School Assessment*[6] (Germann, 1988). In this instrument students must indicate their degree of agreement with a series of attitude statements about science or science in school. I developed an interview protocol to explore children's images of science. This incorporated items from the nature of science interview protocol used by Carey et al. (1989), which probe children's ideas about what science and experimentation are about. Additional questions concerned their self-image with respect to science, the science activities they are participating in, and their feelings about science activities. Earlier versions of the protocol were tried as follow up interviews with children I had worked with as fourth graders last spring, and adjustments were made. (See appendix B.) All interviews were audio taped and transcribed.

As part of my research I have observed (and, at times, participated) in both

[6] I split one compound item into two in the version I administered.

with curiosity about the world and ideas about how science might empower them to do the things they care about. Yet as they progressed through elementary school, this critical aspect of the scientific enterprise was eliminated from their image of science. This is probably because they were not given the opportunity to connect science to their interests, and were not learning to apply scientific method to the topics they were most passionate about. As the children became increasingly aware that certain skills are needed to do and design experiments, their view of science also became more removed from their own goals and aspirations.

5. Study Three: Current Research

My current research continues this exploration of children’s ideas about science. More of a focus is brought to children’s ideas about experimentation and the generation of scientific knowledge. Children’s feelings about science, and about their potential for doing science is also central.

5.1 Methods

5.1.1 Site

My current research is being conducted in a sixth-grade classroom in a public school in Cambridge, Massachusetts. The school is noted for its innovative curriculum, and attracts students from varied socio-economic backgrounds. The classroom teaching is shared by two teachers, who each teach 2 fixed days a week, and alternate the remaining days. They each have nearly twenty years of teaching experience and have developed many learning activities, some in conjunction with researchers from the local educational community. Children are usually involved in individual, pair or group activities, or teacher facilitated whole class discussion. Their work in science emphasizes the importance of “sense-making” (Rosebery, Warren, and Conant, 1992; Theberge, 1994) by the children. One teacher is leading activities involving understanding connections between shadows, the position of the sun, length of day around the world, and the seasons. The other teacher is co-leading (with a science teacher from the school) activities involving building structures and understanding what keeps them up (or makes them fall down). The “structures” activity covers a newly mandated city curriculum requirement for the sixth grade.

5.1.2 Subjects

The subjects are the entire sixth-grade class, which is comprised of 25 students, 13 girls and 12 boys. Most of the 11 non-white students in the class emigrated from Haiti, and were originally enrolled in a bilingual program in the school.

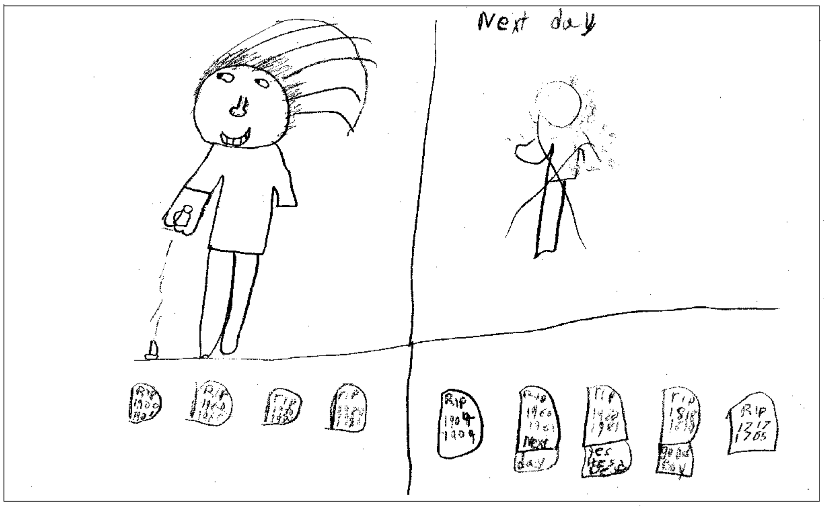

Figure 3: A fourth-grade boy's picture of a scientist conducting a fatal experiment on himself.

4.3 Discussion

Some differences in response between the younger and older children were developmental. Seven-year-olds are more easily influenced than ten-year-olds. This was particularly noticeable during brainstorming sessions. Second grade children frequently made responses that echoed the responses of their peers. Similarly, they gave many examples of "mixing" during a brainstorm shortly after making invisible ink during school science. Because their responses are so easily influenced, it is important to use multiple approaches to probe for young children's ideas and feelings (White & Gunstone, 1992). Repeating questions on separate occasions may also be useful. For example, I found in follow-up interviews with three children that the distinctions they drew between "formulas" and "potions" had changed, but that both were still mixtures of some kind, created to serve some purpose.

Some of the age differences reflected accumulated learning from school, educational television, friend, family and other sources. This included knowledge of more sophisticated topics, as well as more knowledge of the activities engaged in by scientists.

Although the teachers who participated in this study never attempted to talk with children about the scope and goals of science, their choice of topics and activities clearly had a powerful effect on the way the children thought and felt about science. Similarly, these teachers did not address the motivations of scientists with their students. Although the children generally understood that they should study science because it is important, they had no reason to see it as different from any other academic subject that they might or might not like. The contrast between second graders and older elementary school children suggests that the children began information that would be passed down the generations. She thus connected knowledge transmission to a personal source, in contrast to the other girl's use of library books.

Although some second graders drew scientists with elaborate chemistry apparatus (see Figure 2), older children had more knowledge of equipment used in experimentation, However, they over attributed the power of some equipment such as computers. One fourth-grade boy explaining a picture he had drawn of a scientist searching for a cure for cancer, said that the scientist gave the mixture he had made to the computer. "Like, if it is, like if it cures cancer, it would say on the computer. If it doesn't it would say, like, try something else."

4.2.5 Feelings about Science

Children in all grades referred to ways in which science helps us. Second graders mentioned medicines, and formulas to give animals so that they would not die. Older children talked about cures for diseases such as cancer and AIDS. They also linked science to the search for ways to stop pollution and improve recycling.

Science was also seen to have a dangerous side. Children noted that scientists use and make chemicals which can help people or which can be dangerous. One child's picture portrays a scientist who, in the first panel, is testing a formula by drinking it; in the second panel, he is dead. Scientists also produce explosives. Although explosions can be dangerous, they are seen by many children as exciting. A simulated erupting volcano was a memorable science activity. Children spoke of the danger as arising primarily from accidents caused by careless or non-expert practitioners of science.

Fourth and fifth graders spoke less frequently than second-graders about science producing things and effects that they found personally exciting. In talking about what it takes to become a scientist, they focused a great deal on the importance of studying and hard work. School values became a model of science activity, and science was not very appealing to many of these children.

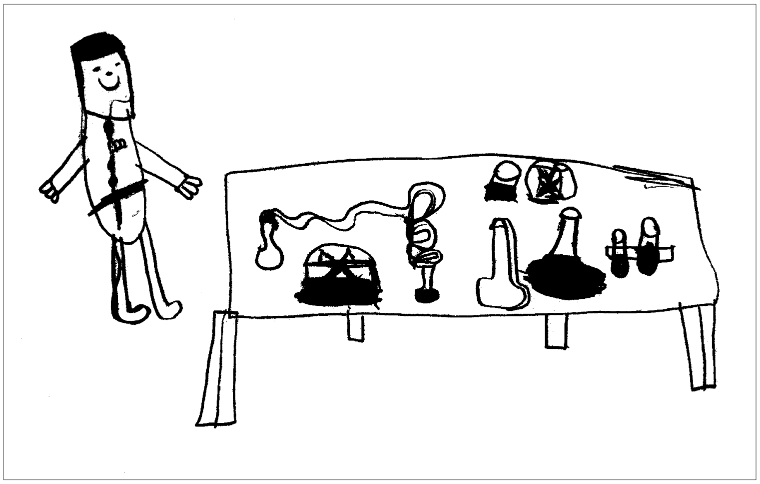

Figure 2: A second-grade boy's picture of a "typical" laboratory scientist.

4.2.3 Experimentation

Children in all grades had two main points of view of experimentation. Some saw it as the testing of somewhat random combinations. For example: "give stuff to lab rats and see what happens." Others saw experimentation as combining things with a goal in mind: "combine chemicals to make a new chemical to stop pollution." This latter response indicates an important positive aspect of science for many of the children: it can be used to help people, animals and the environment.

Knowledge about how to do experiments was often seen as contained in books. One second-grade girl talked about using an ingredients book to find out how to make a formula to "blow up the planet." She then went on to say how she would throw "Library books, like math books and stuff like that" into a pot of boiling water

> So the pot of hot water, and you have the soap in it, then the hot water can have a brain. It can know math, reading, and computer stuff. Then you don't have to know nothing else. And the pot of water does it all by itself. If the pot of water knows that it's right then it'll blow up. The pot will blow up.

With further questioning, she said she "kind of" thought water could really learn from a book. Although her idea about how learning might happen is perhaps unusual, it reflects the fact that the children often do not have an understanding as to how new ideas and experiments can be generated. They therefore assimilate it to ideas that make sense for them. One second-grade girl described how a man knew his great-great grandson was going to be a scientist, and wrote down the needed chocolate."[5] In contrast to these imaginative ideas, the mixtures they mentioned were more prosaic: "mix vinegar and baking soda," "mix baking soda, alcohol and other chemicals, and see what you get." Through interviews I found that these ingredients had been recently used by the school science teacher to make invisible ink.

Activities that fourth graders said that scientists do included: "experiment," "study lots of different things," "make other machines," "explore," "look at different things to see differences," "keep on trying things," "use microscopes," "go to different places to explore," "find new animals," and "make things to help people."

Fifth graders initial responses as to what scientists do were even more similar to those many adults would give: "try to figure out things," "invent things," "experiment," "study animals," "discover new stuff underwater."

4.2.2 Criteria for Science

In the excitement of brainstorming, children mentioned items which appeared to me not to be science, but which had associations to subjects mentioned. For example, some second graders mentioned super-heroes. With some classes I led discussions to clarify which topics were seen as science—super-heroes were not.

Although they did not uniformly agree on what topics are part of science, second-grade children made distinctions between what was and was not science. Some school subjects were introduced as science by classroom teachers, or were science because they were taught by the science teacher. The presence of electricity or electronics also made many items part of science for the children. Some interesting criteria for deciding if something was part of science emerged when I had classes vote on whether different items were science topics, or were studied by scientists. For example, second graders expressed very different opinions about whether or not sharks are part of science. One groups said no—there was not much to learn about sharks. The other groups said that there was a great deal to learn about them. Thus the children saw learning (echoing the item "to learn stuff" in the brainstorming session) as important for science.

For fifth graders novelty—the discovery or construction of new things—was an important criteria for deciding if scientists would study something. Some said that at one time, scientists studied shoes. Now, they know about them, and no longer have to study them. Others said that scientists *do* study shoes. This is necessary to make new kinds of shoes, such as the shoes you "pump up."

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[5] In research on machines I conducted with Edith Ackermann (Brandes, 1992b), children talked about robots of this kind, including robots to do homework.

4.2 Results

This section will present selected findings from studies one and two. A fuller presentation would include case studies, as well as additional topics.

4.2.1 Ideas about Science

The second grader's first responses to the brainstorming question "What is science?" reflect a number of themes that emerged more fully in further exploration. They said science is "magicians who put things together and smoke comes out of it," "to learn stuff," "something like medicine," "electronics," "gasoline," "stuff to make things blow up," "combine medicines to make new medicine," "when you make machines and things," "scientists make stuff, it could taste bad"; and "you could mix chemicals." These themes include : a fascination with the potentialities of mixing things and making things; the potential for science to be both helpful and dangerous; high technology as a salient science topic; and the belief that science involves learning.

Third grader's initial responses to the same question were more connected to school: "when you do a project like make a volcano out of Play Doh," " a way of people coming up with new ideas like underwater golf," "make things, like a tornado in a bottle," "rocks," "put bottles together—soapy water," "studying volcanoes," "studying cliffs," "mess around with wires," "peanuts," "make volcano, lava comes out," "experiments," and "animals." Most of the activities the children mentioned were ones that they had done as part of school science. Growing and learning about peanuts were part of a science curriculum developed by the teacher, which included learning about the life and work of George Washington Carver.[4] After the children mentioned animals, most of their subsequent responses were topics they saw as science.

In mentioning science topics, children in all grades most frequently referred to subjects studied in school, such as plants, animals, planets, volcanoes, and other elements of the natural world. Items involving technology were also listed: disk brakes, robots, computers, and the computer language Logo are some examples. Lists of science topics arose in brainstorms on "what is science?" and "I am curious about." Brainstorms about "science activities" and "what scientists do" included "active" processes, but also gave rise to lists of topics studied in science.

In talking about science activities the second-grade children spoke a great deal about *mixing ingredients* (at least 10 items) *making* things (at least 8 items), *robots* (about 7 kinds), and *formulas* (about 10 kinds). Examples of the formulas were: "to make you sleepy," "to turn a house into gold," and "to make animals talk." They mentioned robots "to make candy," "do homework," and "turn things into

[4] This teacher intentionally decided to build on the work of an African-American scientist. She was aware that the content of science lessons can affect children's images of science.

from 40 minutes to an hour. Each session began with brief instructions (such as telling the children to tell me what they think science is, or what they are curious about); their ideas were listed on a large sheet of paper. At the end of each session, the children were asked to do some brief writing or a drawing related to the discussion. These materials, and the transcribed notes, were used to guide subsequent sessions.

I observed classes taught by the science teacher, as well as sessions led by classroom teachers. I kept field notes, which described activities in the classroom, as well as my own reactions and ideas.

The interviews were shaped by a number of factors. Sometimes I followed up on topics that had been explored in the brainstorming sessions, such as "What are you curious about?" The children's writing and drawing helped to elicit responses. My analysis of the brainstorming sessions also led me to ask specific questions about such topics as potions and formulas. However, much of the time a child and I discussed topics that evolved in the course of the interview. For example a discussion of a LEGO car competition led to the topic of gravity. A lengthy discussion of "zero g" ensued, which I pursued further in a subsequent interview. I also asked the children about their experiences with science classes. This included what they did, what they learned and whether they liked it. All interviews were audio taped and transcribed.

4.1.4 Subjects: Study Two

The subjects were students in one classroom each from grades 2 through 5. One purpose of these sessions was to look for developmental differences between the younger and older children. The second-grade teacher was the same for both studies.[3]

4.1.5 Methods: Study Two

Classroom brainstorming sessions, clinical interviews, and small group projects were used over a four month period beginning February, 1993. With each class brainstorming sessions about science were conducted. Children were also asked to draw a picture of a scientist. Fantasy experiments (which are described in more detail in section 5.2) were conducted with several children, across the range of grades, but results will not be described in this paper. The majority of the effort in this study was directed towards the fourth-grade classroom. Further brainstorming sessions with these students explored their ideas about scientists and doing science. Interviews were conducted with 7 fourth-grade children. New questions focused on concepts such as prediction, and experiment, and on eliciting the children's attitudes towards science. I also conducted small group projects with the fourth graders which will not be discussed in this paper.

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[3] A study of this teacher's approach to teaching is contained in (Brandes, 1992a).

which some 7th graders exhibited in the study of Carey et al. (1989).[1] This third study, which is currently in progress,[2] continued to investigate the first two questions, and in addition asked:

> 3) What is the relationship of children's feelings about science to their ideas about science and science learning?
>
> 4) What activities can help children pursue their science interests?

4. Studies One and Two

4.1 Methods

4.1.1 Site: Studies One and Two

The site was a predominately Hispanic and African-American inner city Boston public school. Built as an open school in the 1970's, that model of education was never put into practice. Today the few rooms with four walls are considered prized territory by most teachers, who value insulation from the noise of adjacent classrooms. Most of the classroom teachers do little or no science teaching themselves. Students work with a science specialist about once a week. I chose the site because two years of previous support work (Brandes, 1992a) and research (Brandes, 1992b) in the school gave me connections and credibility with the teachers and principal.

4.1.2 Subjects: Study One

During the first phase of the study I worked with a classroom of 28 second graders. Based on my classroom observations and the initial interview I selected three children, who appeared to have differing relationships to science, to interview in depth. Over the course of the project, each of these children was interviewed four times in the second grade and twice during their third-grade year. In addition, nine other second graders were interviewed at least once.

4.1.3 Methods: Study One

Three main methods were used during a three month period beginning in February, 1992: classroom brainstorming sessions, clinical interviews and ethnographic observation. The project began with a series of audio taped brainstorming sessions, conducted to gain an overview of the children's ideas. The sessions varied in length

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[1] The first school only went up to fifth grade.

[2] Hence results reported here should be considered preliminary.

developing a "feeling for the organism" (Keller, 1983).

In summary: children construct images of science, which are comprised of an interconnected complex of mental representations and feelings. This construction is influenced by cultural messages and school experience. In consequence, many children feel science is not for them by the time they leave elementary school. Yet it is possible for children to experience aspects of doing science which may lead them to a deeper understanding of the enterprise of science, and a greater feelings of self-identification as a person with abilities in science.

3. Overview

The ideas in this paper have been developed during three studies, conducted in public schools during the spring semesters of 1992, 1993, and 1994 (ongoing). The first two studies were conducted the same inner city school, employed many of the same research methods, and were guided by the same research questions. For this reason, both studies will be presented and discussed in section 4. The third study is more intensive, and builds on and expands the work of the first studies. Therefore results of this study are presented in a separate section. The remainder of this overview will present the goals of the three studies.

Studies one and two were guided by two questions:

1) What are elementary school children's ideas about what science is and what scientists do?

2) What, in science, are children curious about?

The first study explored the ideas of a classroom of second graders. The second study focused primarily on fourth graders, but also generated some data about second, third and fifth graders. Both studies involved brainstorming sessions with entire classes, and individual interviews with children. They led to a preliminary understanding of the development of children's ideas about science.

Several observations from these studies led me to refine my ideas and methodology. One observation was the decrease in overall excitement about science as children progressed from second to fifth grade. Furthermore, by the fourth-grade students seemed more labeled (both by teachers and by themselves) as good or not good in science. This led me to add a focus on the affective elements related to science, and how they might interact with ideas about science in an *image* of science.

In order to study children's images of science in a setting which provided students with a better in-school science program to build on, I chose a new site, a sixth-grade classroom known for its innovative science activities. The use of a sixth-grade classroom was also motivated by an interest in features of children's epistemology of science which I did not find present in the fourth-grade students, but the Boston Museum of Science (see Figure 1) portrays a wild-eyed boy with glasses and a pocket protector, bearing the subtitle "If your little scientist misses this exhibit, he'll be really mad." The tag line reads "After all you never know who will be the next Einstein. Or Frankenstein." This ad compactly presents a stereotyped image of a scientist as a nerdy white male genius, perhaps a bit mad, to be handled with care. It suggests that even if you, yourself, feel alienated from science, it is your duty as a parent to see if your child might be one of the few who have the ability to enter this odd elite, and perhaps advance the cause of humankind. Despite the fact that the Science Museum is dedicated to the popularization and explication of science, the ad is a powerful exemplar of the mystification and alienation people feel from science. This myth prevents many people from coming close enough to science to experience their own potential for enjoying and doing science.

A core motivation of my research is my belief that science need not be either as alien or as mysterious as many people come to see it.

2.3 School Science as a Source of Alienation

School science often fails to convey the wonder and excitement of doing science, leading to reduced student interest. The view of science as a "storehouse of knowledge" ignores the process by which such knowledge is generated (Tinker, 1991). Approaches which emphasize science process skills often fail to convey the motivation for the use of such skills in an ongoing cycle of theory generation and verification (Duschl, 1990). The formally presented scientific method does not fully reflect the actual "messier" practice of scientists. Covering up the "messiness" of real science or mathematics can lead to brittle learning and be damaging to learner's self-esteem (Wilensky, 1993). Yet everyday and expert learning activities bear striking similarities when contrasted with school learning and thinking (Brown, 1989). A goal of my research is to use such similarities to help children engage in science and construct richer, non-alienated images of science.

2.4 Potential For Enriching Children's Images of Science

One goal of this research is to help children build connections with aspects of science that are personally meaningful. Some aspects of science that are potentially accessible, but often absent from school science are: 1) the importance of curiosity and a sense of wonder in motivating scientists' work (Nemirovsky, in press); 2) the value of many different skills for doing science (e.g., tinkering and building things is necessary to create the tools and instruments that are an important part of science); 3) the importance of communities of research, which differs from the common image of the solitary scientist (Latour, 1987); and 4) the importance of multiple ways of scientific "knowing" (Belenky, Clinchy, Goldberger & Tarule, 1986; Turkle & Papert, 1991; Wilensky 1991, 1993). Although science is often seen as distant and objective (Keller, 1985), Barbara McClintock was able to see and understand far more than other researchers about the development of the genetic material of corn, by roles of epistemology are reflected in a key concept for this study: *image of science*

2.1 Children's Images of Science

The concept *image of science* incorporates both cognitive and affective components. Cognitive aspects include ideas about which topics are part of science, the activities of scientists, and the nature of the scientific enterprise. Important affective aspects include the child's feelings about science—the interest, dislike, indifference, and excitement they experience in relation to science. In addition, this affective dimension includes science related self-esteem, which is reflected in statements such as "I want to be a scientist" and "I'm not good at science." The cognitive and affective elements of image of science are inextricably interconnected. If an African-American girl's image of "what scientists do" is a white man working alone in a laboratory of shining glassware, this image may both create and reflect a feeling of distance and inadequacy with regard to science.

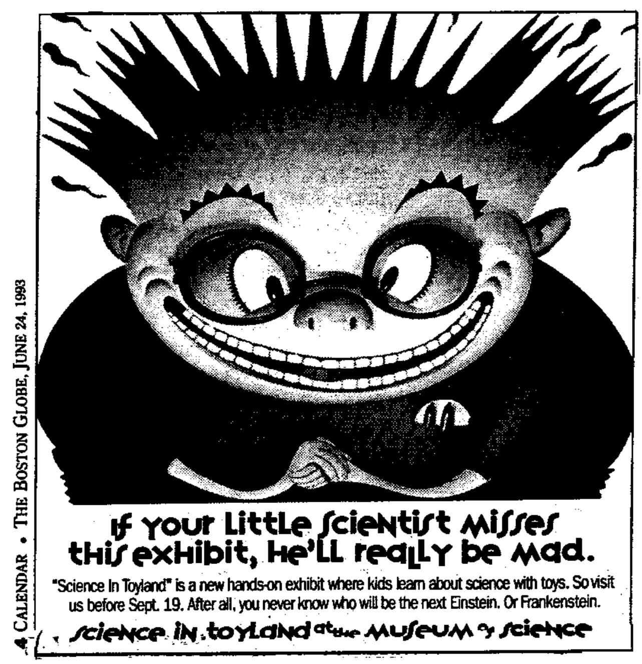

Figure 1: Advertisement for Museum of Science, exhibiting stereotypical characteristics of a scientist.

2.2 Cultural Stereotypes as a Source of Alienation

Children's images of science are influenced by societal images of science, portrayed in books, movies, advertisements, and other media. For example, an advertisement for

of Technology in Learning. Presented at the National Educational Computing Conference, Boston, MA, June 1994. MIT Media Laboratory, Cambridge, MA.

1. Introduction

"If you need an apple seed to get a tree, and a tree to get an apple seed, where did the first tree come from?" This key question about the origins of life was posed to me by a bright, inner-city second grade girl. Despite her curiosity about the natural world, her insightful contributions to class discussion, and her ready adoption of new concepts, this girl insisted that she was "not good at science." What is her image of science, that she sees herself as "not good at it"? What can be done to help her construct an image that incorporates the questioning and curiosity that she, herself, has in such abundance? The underlying motivation of my research is to improve children's relationship to science by helping them construct a richer image of science, one that reflects the world and work of scientists and connects science to their own abilities and activities.

This research explores the ideas and feelings about science of an ethnically diverse group of children in grades two through six, using drawings, questionnaires, brainstorming sessions, ethnographic observation and clinical interviews. In this paper I present some findings to date, and the framework and motivation for work in progress. This current work involves working with children in science explorations. It is rooted in questions they generate, and aimed at helping them understand in a deeper and more concrete (Turkle & Papert, 1991; Wilensky, 1991) way the process by which scientific understanding is generated.

2. Framework

This research builds on Piaget's (1954, 1970) idea that our knowledge is constructed through an on-going interaction between our environment and our current understanding of the world. It explores children's construction of their image of science. Although children's ideas may not be as explicit or coherent as formal theories, they are robust, as is indicated in the literature on "children's ideas" and "conceptual change" (e.g., Carey, 1985; 1991; diSessa, 1982; Driver, Guesne, & Tiberghien, 1985; McCloskey, 1982; Posner, Strike, Hewson, & Gertzog, 1982). Their beliefs about what science is can dramatically influence their interest in science; a major objective of this research, therefore, is to show how children's science activity can help enrich their beliefs.

This work also draws on studies that explore the role of epistemological beliefs in learning (Ackermann, 1987; Hammer, 1991; Wilensky, 1993). My current research will extend the work of Carey, Evans, Honda, Jay, & Unger (1989) exploring children's ideas about the nature of science. A difference in my approach, however, is the integration of the role of affect. The increased attention being given to the role of affect in conceptual change was highlighted in a recent review article by Pintrich, Marx and Boyle (1993). The importance of children's construction of ideas, and the

ELEMENTARY SCHOOL CHILDREN'S IMAGES OF SCIENCE

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ABSTRACT

This paper introduces the framework of *image of science* as a tool for understanding and enhancing children's science learning. A child's image of science incorporates both cognitive aspects, such as ideas about science, scientists and experimentation, and affective aspects, such as identification with, or alienation from, science. It is argued that there are aspects of science accessible to elementary school students, which could help enrich their images of science, and potentially enhance their science learning. Results from three studies show the development of children's images of science, from grades two to six. Although children's ideas about science in some ways become more sophisticated with age, their excitement about science decreases. Furthermore, the process by which new knowledge is generated remains mysterious, leaving most children on the "outside" of science.

In Y. Kafai and M. Resnick (Eds.), *Constructionism in Practice: Rethinking the Roles*