PETS: A Personal Electronic Teller of Stories

Jaime Montemayor, Allison Druin, & Jim Hendler
University of Maryland,
Institute for Advanced Computer Studies

A Story

Let us start by reading a story written by a seven year old child, entitled *Michelle*.

> "There once was a robot named Michelle. She was new in the neighborhood. She was HAPPY when she first came, thinking she would make friends. But it was the opposite. Other robots threw rocks and sticks. She was SAD. Now no one liked her. One day she was walking down a street, a huge busy one, when another robot named Rob came up and ask [sic] if she wanted to have a friend. She was SCARED at first but then realized that she was HAPPY. The other robots were ANGRY but knew that they had learned their lesson. Michelle and Rob lived HAPPILY ever after. No one noticed the dents from rocks that stayed on Michelle." (Druin, Research notes, August 1998)

This is just one of many stories that children have written with the help of PETS (Druin et al. 1999a). The author of *Michelle* did not just write this moving story; she is also an integral member of the team that built our robots. As you read on, PETS will be further described. Our motivations behind building such an interactive robotic pet will also be discussed. In addition, the process of how we made this robotic technology with our team of adults and six children will be introduced. And with this, we will present *cooperative inquiry* (Druin 1999a), the methodology that we embrace as we discover insights about technology, education, science, engineering, and art. Finally, this chapter will close with reflections on what was learned from on-going research effort.

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Who, or What, Is PETS?

Figure 1: PETS, Spaceship, and MyPETS software

What Does PETS Do?

PETS is a Personal Electronic Teller of Stories, a robotic story telling environment for elementary school age children (Druin et al. 1999a). The PETS kit contains a box of fuzzy stuffed animal parts and an authoring application on a personal computer (Figures 1 and 3). Children can build a robotic animal, or pet, by connecting animal parts such as torso, head, paws, ears, and wings. After they construct their pet, they can write and tell stories using the *My PETS* software. Just as the robotic animal is constructed from discrete components, *My PETS* is also constructive. This application enables children to create emotions, draw emotive facial expressions, name their robotic companion, and compile a library of stories and story starters.

Each emotion that the robot performs is a sequence of physical movements that conveys a specific feeling to the audience. Our child designers defined six basic emotions: happy, sad, lonely, loving, scared, angry. They were chosen because the actions that represent these emotions are sufficiently different from each other that the audience would not confuse one from another. For example, a lonely robot droops its arms down, and looks left and right for a friend. If the robot is happy, it would wave its arms real fast, turn its head left and right, and spin the spaceship it rides in. And, when the robot is sad, it droops its head and arms, and moves forward at a slow, deliberate pace (Figure 2).

Figure 2: emotions and their corresponding set of actions

PETS encourages creativity through interactive and iterative play. Children are constantly writing and rewriting their stories, and in the process, developing their own writing styles. They also enjoy building different kinds of animals. Whenever they want, these children can direct *My PETS* to tell the story and watch their animal act out emotions. As the robot encounters an emotional word in the story, it performs that emotion by moving its body in the sequence specified by its creators.

Collaborative learning is an important feature of PETS. Within a group of children, some enjoy writing stories; others like to construct physical things. Together, they become the authors, choreographers, and directors, creating narratives replete with emotions and actions.

A critical feature of PETS is that the child user is always in control. Unlike products such as the Actimates Barney, where the robot directs the flow of action, and the child follows its instructions, we believe that children should decide their own activity patterns. Many other researchers and industry developers support this constructive approach. For example, KidSim/Cocoa (Cypher & Smith 1995), LOGO (Papert 1980), LEGO, etc. all place the child at the center of creative play. In short, children are intelligent beings and should have the freedom to create their own imaginary worlds and invent their own play things.

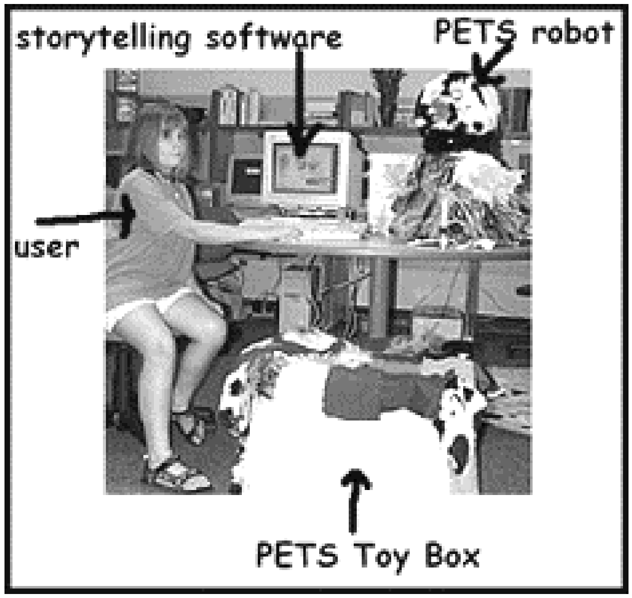

Figure 3: the $PETS_1$ storytelling environment

How Has PETS Changed?

Over the past year, we designed three versions of PETS. We call them, in the order of creation, $PETS_0$, $PETS_1$, and $PETS_2$. Each successive version is a more refined "sketch" of our group's collective vision of the storytelling environment.

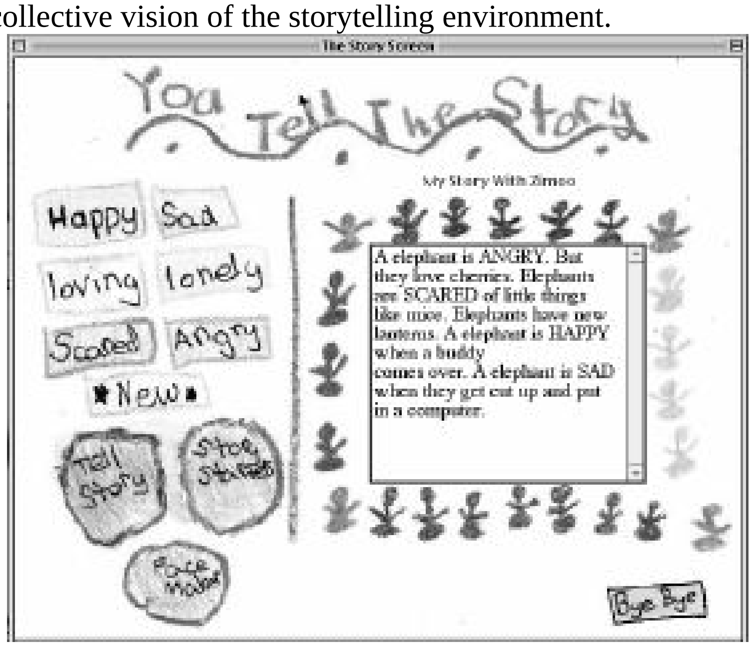

Figure 4: Children type their stories and insert emotions in The Story Screen.

$PETS_0$ was a prototype that the adult designers created to understand the technical issues related to interactive robots. As we will show later, this version was a critical step in our design of future iterations. $PETS_0$ is in fact the result of the adult members' *technology* *immersion* process. The knowledge we gained from building this robot became a rough technology roadmap for future versions.

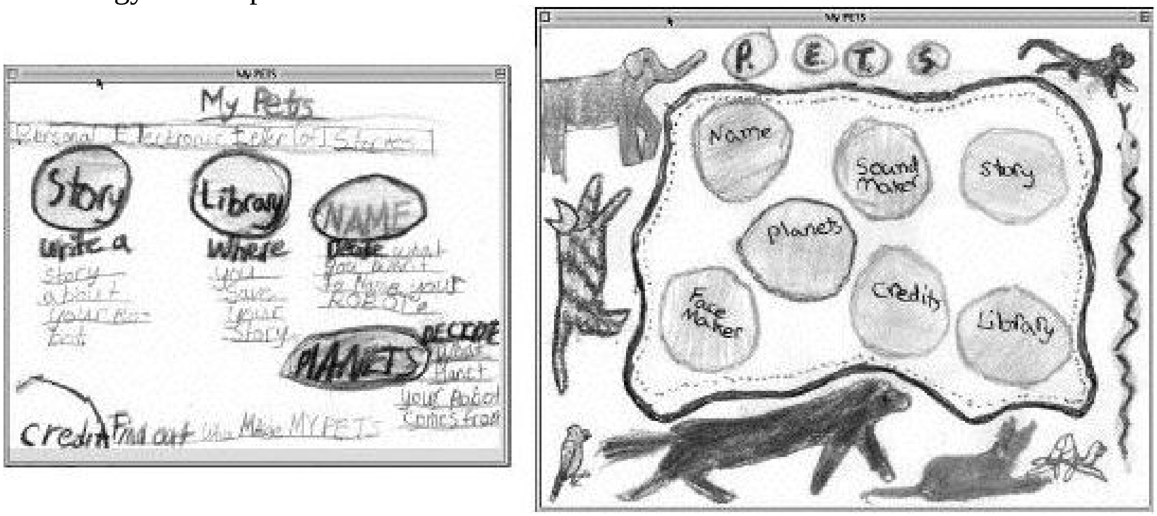

Figure 5: main screens of the *My PETS* application; the left is from $PETS_1$, the right is from $PETS_2$

$PETS_1$ was the first "full-featured" and demonstrable robot from our *intergenerational design team*. This machine had primitive reactive behaviors. For instance, its head would follow or turn away from a beam of light, depending on its mood. Also, it would move its paws toward you if it is happy, or pull away if its is scared. Most of its skeletal structure was constructed of LEGO blocks, and the limbs were simple plastic boxes. Various fabric materials covered the robot to hide the mechanical components. For instance, the head was covered with a fabric with cow hide prints; some limbs were feather; and a furry skirt draped over the entire body to give the robot a rounded and soft shape. A Handy Board (Martin 1998) micro-controller, within the torso, controls various embedded motors and servos. In addition to on-board programs for the robot's primitive behaviors, the controller also receives commands from *My PETS* through a connecting wire. Finally, sensors (e.g. light, touch) throughout the body inform the robot about its environment.

Figure 6: $PETS_1$, with a furry body, dog paw, duck foot, and cow face

Our current prototype, $PETS_2$, includes many refinements over its predecessors. For example, $PETS_1$'s software implemented only the reactive layer of a generalized three-tiered behavior based architecture (e.g. Bonasso et al. 1997). In contrast, $PETS_2$ has an additional sequencing layer. This change allowed us to remove a large portion of the program from the microcontroller over to a more powerful and flexible desktop computer. It also greatly simplified the code underlying the user interfaces we used to control the robot.

Figure 7: the MyPETS software, the transmitter box, and the skeletal components of $PETS_2$

After we completed $PETS_1$, we set three major goals for the next version: aesthetics, durability, and wireless communication. $PETS_2$ has a foam outer-shell covered with felt (Figure 7). It has far more graceful shapes and delightful colors. The foam shell not only provides the outline of the robot; it is also a buffer against abusive play from children. In addition, it has a much sturdier skeletal structure built from metal, plastic, and polycarbonate materials. Finally, the robot now communicates with *My PETS* via wireless radio frequency channels (Figure 6).

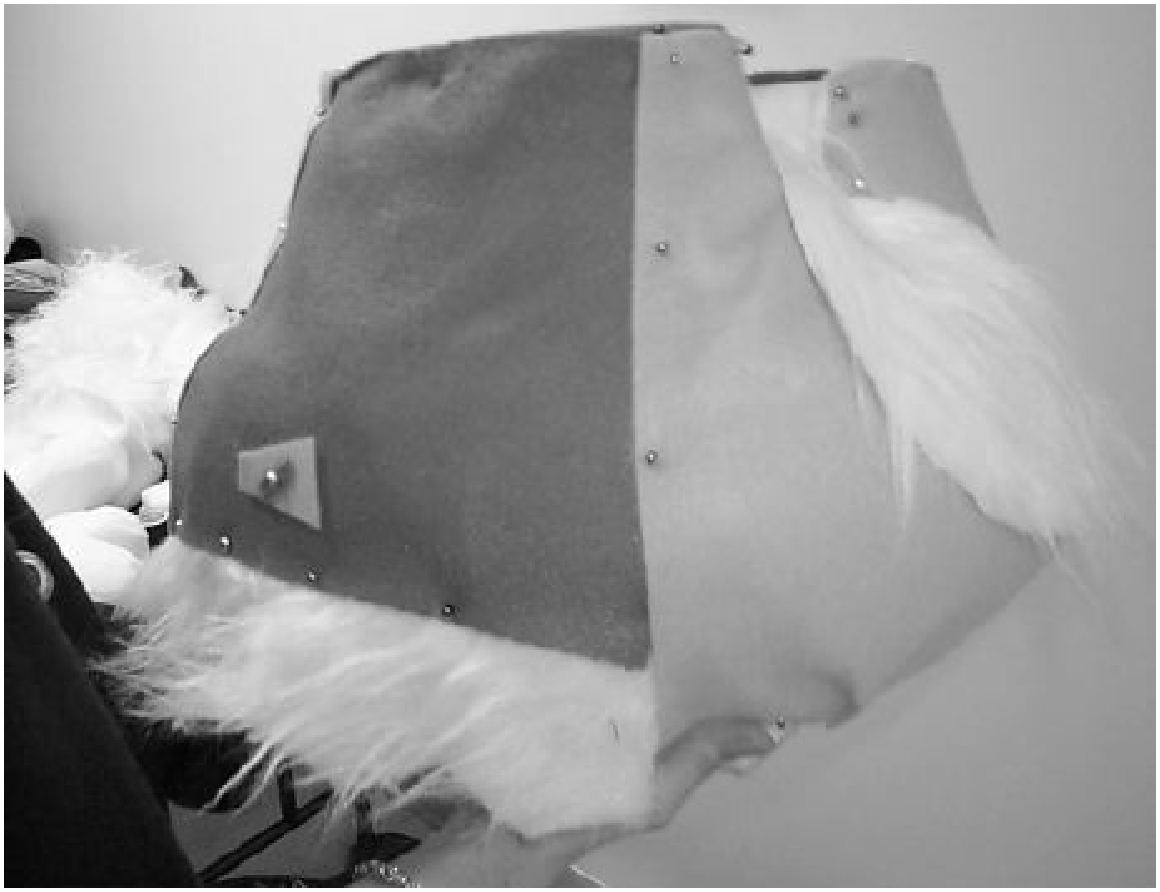

Figure 8: the foam shell (torso) of $PETS_2$

Why Build An Emotional Robot To Tell Stories?

Why a Robot?

Children are drawn to physical play things. They love robots! We saw this repeatedly over the past year, as we demonstrate PETS to young visitors. As they enter our lab, inevitably, they are drawn to the robots in our room, even though it is filled with lots and lots of other technological goodies. We believe this is because robots are inherently intriguing and highly interactive objects. Indeed, studies have shown that in settings where there are both things to observe and things to play with, young children are usually attracted to activities where they can become interactive participants. For example, in zoos, they prefer to interact with pigeons and squirrels than the more exotic animals behind bars (Greenfield 1984).

Accordingly, a robot as a design goal is useful for two reasons. The first is that it is much easier to get the children to be excited about inventing something they like, than to create the next generation toaster oven, for example. The other is that the process of building robots is inherently collaborative and physical. Since we are interested in both the process and the product, having a project that requires collaboration and lots of construction helps us study and test our design methodology in action.

But we have found that interactive, robust, and child-friendly robots are notoriously difficult to make. We believe that there are two main reasons: First, a project such as ours requires an interdisciplinary effort, thus, a team with diverse talents. Putting together such a group is not easy. Second, interactions between a robot and its environment are often unpredictable. This uncertainty presents many technological and scientific challenges.

Because robots are difficult to make, and because the development process requires strong collaboration, they are ideal subjects for our research in technology and methods.

Why an Animal?

Children are naturally drawn to animals; these creatures come in so many shapes and sizes. Animals are intriguing things: they can fly or hop or slither about. It is just plain fun to watch them and then play with them. No wonder libraries are filled with storybooks about animals. On television and in movies, Muppet and Disney characters are some of the most enduring memories for many of us. Many of us can still recall the joy of visiting zoos when we were young. In addition, people make emotional connections with animals. Some visitors have observed that in our storytelling environment, children can share their feelings through a safe surrogate, which means they feel freer in discussing difficult emotional issues.

Just as important, our younger members have been quite specific that they wanted to build things that are warm and fuzzy; they don’t want the “cold” “hard” and “metallic” look-and-feel of classical robots (Druin et al. 1999a). Indeed, because of technical challenges related to creating “furry, fuzzy” robots, the adult members have on several occasions asked whether being “huggable and cuddly” is a requirement. And each time our kids responded unequivocally, “Yes!”

This theme has become a fertile area for commercial endeavors and academic research. Microsoft (Strommen 1998), Tiger Electronics (Furby), and Sony (Fujita and Kitano 1998) are actively promoting robotic animal products. At MIT’s Media Lab, researchers are also developing plush toys to control synthetic characters in animated environments (Johnson 1999). Another project, SAGE, also uses a programmable stuffed animal to tell stories (Umaschi 1997).

Why Stories?

People love stories. From their earliest moments, children love to listen to stories. Either as parents or children, many of us have fond memories of our favorite bed-time stories or books. Stories preserve our cultures and histories, enable us to communicate our ideas and feelings, and educate learners of all ages (Bruchac 1987, Gish 1996 and Ortiz 1998).

Storytelling and story-making can be immensely creative and empowering for children. They decide what they want to say and how they want to say it. The only requirement is that the person has a way to express her ideas. A story can be made of words, or pictures, or sounds, as long as it conveys the message of its author. From the beginning, we made this a functional requirement for our new technology, since it is such a natural way for children to explore new ideas and feelings.

Why Have Emotions?

It is difficult to imagine a robotic animal devoid of emotions. Observe how children play with stuffed animals or action figures. Their play is filled with emotive content (Goldman 1998). They attribute emotions to their toys, whether they are dolls or trucks. So it would be natural that when children interact with a robot, especially one that looks like an animal, they will relate to it emotionally. Indeed, how can you tell stories without including emotions within them? It just does not make sense.

Our Team And Our Laboratory

Figure 9: Kids (team members and visitors) play with the *MyPETS* software.

When people discuss the design processes, they usually refer to the result of that process, or the technology. For us, our design goal is a new kind of educational technology, one that incorporates many different constructive and collaborative learning experiences. This is important, but we are also equally interested in the development process and the learning experience that comes from building and studying technology. Many researchers have referred to this type of learning as outcomes of cooperative or participatory design process (Ehn 1993, Greenbaum 1993, Mumford and Henshall 1979/1983). Educators (Lave 1992) also call it a community of practice. Allison Druin describes this as "... a community of people with different skills that learn as they work toward shared goals", (Druin 1999a).

We want to invent new methods for learning through technology, and we want to know about the kinds of learning that can occur in adult and children, when they collaborate as equal design partners.

The Intergenerational Design Team

Figure 10: our team talks about the structure of PETS

Our team, the *intergenerational design team* (IDT), has at least twelve members. Six of us are between seven and eleven years of age, and come from local (public and private) elementary schools. These children stay with us for a long term, at least for one year. The adults are undergraduate, graduate students, and faculty from art, education, engineering, and computer science. We share a common goal: to understand how children are interested in and wish to play with new and existing technologies. This investigation led us to develop our robot and the principles behind *cooperative inquiry*.

It is clear to many people that our team should include people with many different specialties. For example, the mechanical engineer would design and build the physical structure of the robot. Of course, given enough time, anyone might be able to do this. And she (the non-mechanical engineer) would surely gain valuable learning experience. But although this may be an enlightening learning process, it is probably not a very efficient way to develop products. Similarly, we can see how the other experts are integral to the team. The educator guides us and shows us ways to collaborate with children. She also provides the framework for our design process. The artist transforms our “cold” and “ugly” machine into a huggable and lovable companion. And the computer scientist creates the programs that enable children to write the stories to make the robot come alive with emotions.

But it is not obvious to observers why we include children as equal partners on our team. This deserves a more serious discussion, and we will offer our reasons in the next section.

Why Children?

We are often asked why we include children on our design team as equal-voiced partners. After all, many would suggest that it’s difficult enough to have a good working team of adults; there is no need to make the development process more complicated by including young people who (presumably) don’t know one-tenth more than grownups. Visitors of our research lab ask the following common questions: “How do you work with children?” “How do you select the ‘right’ child for the group?” “Won’t they slow down the development process?” “Why do we need them? After all, we were all young once, so we should know what and how children think.” The common underlying question seems to be this: Can children be effective partners, and, are they qualified? After spending over a year with our young members, we believe the answer is decidedly affirmative.

Here is an example that shows how adults may be less effective than children in reporting flaws in a program. Consider how grownups use software programs. In particular, an adult who uses a business application at her workplace. When she uses a program that does not feel intuitive, she may curse and complain about the awkwardness, but since she has a job to do, she might change her own work pattern to circumvent the flaws. So while the program may not provide her the highest productivity, it still gets some work done. Still, the user might have misgivings about her time on the computer and she certainly would not enjoy using it. Here, we see that adults compensate for flaws in technology.

Contrast this with technology that is designed for children. Any imperfections in a product become magnified many times when a child uses it. She has no patience for things that are not "just right." Furthermore, she has no incentive to change her behaviors just to complete her task; she may just as likely abandon it.

In recent years, industry has come to understand children’s needs and most commercial technological products for children are evaluated and tested by young people before they are produced commercially.

How do you work with children?

It is difficult to work with children to design technology. There are many reasons why this is the case. For instance, young children have more difficulties verbalizing their thoughts than adults. This is particularly the case when they want to convey abstract ideas (Piaget 1971 and Piaget 1973). So unless we acquire the skills to properly communicate with them, it would be difficult to involve them in development efforts. In addition, while there has been an immense amount of research into communication channels among adults of varying skills, it has only been in the past decade that we have come to understand ways to work with children. Also, traditional types of relationships between adult and child, such as speaker-listener, child-parent, or instructor-follower, are not always useful in collaborative settings. Finally, misconceptions about the proper roles of adults and children can often lead to frustration. For example, children are not "just short adults," implying they are equally capable of any task that an adult can handle. We would never expect a seven-year old child to solder wires or operate heavy machinery. Alternatively, just because a child utters a statement does not necessarily mean that it must be followed, since she should always know what's in the best interest of young people. In short, children are an entirely different user population with their own culture, norms, and complexities (Berman 1977), and they should be treated as people with special knowledge about the subject of "being child;" just as engineers are people who know a lot about building things.

As long as we understand that children are a kind of specialist, we can effectively engage them in the design process. We have found that a child can participate in the technology development process in four ways: 1) user, 2) tester, 3) informant, and 4) design partner (Druin 1999b). As Figure 8 shows, each level of participation encompasses the lower level. For example, a tester needs to be a user in order to test a product. Below we will briefly describe each of these roles (see table 1 for the summary of children's roles in technology).

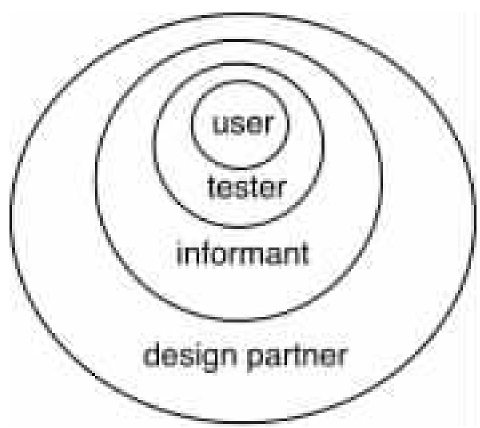

Figure 11: the four levels of involvement in a technology team

Both user and tester offer feedback to designers, either directly or through observations by researchers, about the usefulness, effectiveness, and correctness of a product. The major difference is that the user tests a technology after it is completed and unchangeable, while the tester uses intermediate pre-released prototypes as well as the final product. It is clear that as a user, the child has little impact on the design of a technology except for its future iterations, if they do happen. However, the child tester can affect change in technology, since her preferences and dislikes can affect internal versions of a product. Notice that the idea for a technology originates from adults. The child is brought into the process as an evaluator of the adults' efforts and ideas. These two roles are appealing for adult researchers because adults can more easily control the design process and they are easy roles for children to assume, little learning need happen.

The role of child as informant has became prominent very recently (Scaife & Rogers 1999). In this capacity, the child can have an impact on technology from the start of the development process. The child can participate based on what the researchers believe a child can offer at various stages during product development. Here, the researcher still holds majority control, since she decides when to involve the child. The final role, that of design partner, is where the child has the same stake throughout the entire design and research process. So, unlike the participant, the child partner is not brought in and out of the development; she is always involved. But this level of involving children can slow the development process. Although this is not necessarily bad. In our experience, the slow down is usually due to discoveries of better ways of doing things or new ideas/features that should be included into a technology because the children partners were able to see things that the adults did not.

It is up to the development team to choose the role for their young members. Depending on the team's philosophy, resources, time constraints, a different role may make more sense. In industry, the role of child as tester can be indispensable. It would just be too expensive to release unusable technology. But educational researchers may prefer the user role because it makes observations and evaluations much easier. If you want to involve children as informant or partner, then you should be prepared for longer development time. And, you should be willing to deal with additional problems of working with young people who are far from being adults.

Role of child	Began	Strength	Challenge	In use by
User	Late '60s/ Early '70s	• Easy to include children • Researcher in control • Can suggest future directions in HCI & education areas	• Less direct impact on changes in technology • Children have less say in changes • Educators need time to accomplish	Primarily academic researchers
Tester	A few examples in the 1970s—Began primarily in the late '80s/ early '90s	• Begins to empower children • Quicker input for changing technology • Methods can be done in and out of schools	• Children don't have input until later in the design process • Can offer surprises to adults • Adults decide what can be done given limits of schedule	Academic researchers & Industry professionals
Informant	A few examples in the 1980s—Began primarily in the mid '90s	• Empowers children • Brings children's input into the start of the development process • Flexible when children and researchers work together	• Adults still decide when to bring children into the design process • More time is needed to work with children	Academic researchers & Industry professionals
Design Partner	Mid 1990s	• Empowers children throughout development experience • Children and adults can change and learn from the experience • Instant feedback from children throughout the design process	• Team decisions must be negotiated between adults & children • More time is needed to work as partners • School environment is difficult to work within • Difficult finding researchers that can work with children	Primarily academic researchers with industry professionals beginning

Table 1: A summary of the role of child in the design of technology (Druin 1999b)

How do you select the 'right' child for the group?

This is usually the first question we get after visitors sit through one of our design sessions and meet our children. Implicitly, they might believe; a) these kids are intellectually above the norm; b) they have played with technology for years; or c) they are natural team players. In fact, these children are no different from others in their age group. Some are bright, and some have used computers for several years. But they all have had to learn new things and forget bad habits to become productive members. Every child has her own talents and weaknesses. For example, many had never participated in groups before, so collaboration was difficult for them. A few of our children were shy and quiet, and they did not like to express their ideas in front of the group. But, six months into our project, these children blossomed into fully participating partners. They fought for their ideas to be heard and they openly criticized opinions that they believed were wrong. More importantly, they gained new confidence, whether in technical skills or in social skills, and they began to believe and realize that they were truly "partners."

We require only four attributes from prospective child partners. The first is that the child must be enthusiastic about playing with technology. The second is that the child must be able to express her ideas (e.g. write, speak, draw, paint, etc.). Third, she should be open to collaborate with other children and adults. Finally, she should be between seven and eleven years old, an age we have found most appropriate for this kind of design partnership. Children are old enough to be self-reflective, but young enough to be open to new ideas.

Won't they slow down the development process?

Yes, children can slow down the design process. Products can take longer to build. This is especially true for a new team. Our experience shows that it takes about six months before an intergenerational team becomes a cohesive unit. Consequently, the ramp-up time is significant. Also, since there are many more forms of communication for adults to recognize and understand, this means that the same conversation might be repeated several times, over different channels; this extra effort translates to more time. Alternatively, the design process can slow down just because children can offer insights into better technology that we often decide to incorporate as new features and ideas that were not part of the original design goals.

But consider what might happen if adults try to build technology without incorporating children, using one of the previously defined roles, into the development process. Here is a hypothetical scenario:

a) Grownup has a "great" idea for new technology for kids.
b) Grownup builds it.
c) Grownup shows the gadget to kids and asks, "What do you think?" And, "What should I do to make it better for you?"
d) Kids look at grownup and mumbles "I dunno," or "I don't understand," or "I don't like it."
e) Grownup tries to rephrase "What do you think?"
f) Kids mumble and walk away.

Does this sound familiar? What happened? We believe this gulf in communication is the phenomenon of two monologues. What appears to be an interaction, or dialog, is really just the two sides trying to guess at what the other is really saying. There is no transfer, or flow, of information. Let us look at steps c) through f) again.

Adult's Perspective	Child's Perspective
Grownup shows the gadget to kids and asks, "What do you think?" And, "What	Whah! Information overload! What's all that stuff? What's

should I do to make it better for you?"	going on? Why are these things purple? Why is that thing round?
Kids look at grownup and mumbles "I dunno," or "I don't understand," or "I don't like it."	Just say anything.
Grownup tries to rephrase "What do you think?"	Child thinks, "Hmm. I don't like purple. Therefore, I don't like this thing." Child says "I dunno?"
Kids mumble and walk away.	Who was that?

The problem is that children have no context in understanding the object presented before them; and grownups have no context in understanding how children comprehend their environment. Consequently, when all a child sees is the technology, she cannot understand the rationale behind its features. Now, the adult might try to decipher the ever so deep "I don't like it." But, she may very easily misinterpret the child, because that is just not enough information to work with. And if she does misinterpret her observations, and if she then tries to create a new iteration based on this false interpretation, then the technology may stray from its intended objective.

Why do we need them? After all, we were all young once, so we should know what and how children think.

Yes. We were all children at one time. But designing technology for children based on personal memory is probably not a good idea. First, we overestimate our ability to remember our past. Do I really remember what things I liked 20 years ago? More importantly, do I remember the reasons that I liked certain things? In addition, we grew up in a very different time from today's children. Some of us still remember the vacuum tube television, vinyl phonograph albums, etc. Compare that to what our kids have today: inexpensive home computers, VCR, camcorder, Walkman, etc. The context within which we grew up is not comparable to the current generation. Even if we do remember what was fun and useful, it is doubtful that knowledge easily applies to designers of technology for the future. So, we need to include the children's voice in our development efforts. They give us their perspectives for today, not twenty years ago.

Some Insights From Our Kids

During our many design sessions, our young members offered many refreshing insights. Some of them the adults might have come up with eventually. But there were many great ideas that may never have come to light had adults been the only ones doing the thinking. We will share four examples: the story starter, the planets, the emotions, and the emotion construction interface.

Story Starter

When we were designing $PETS_1$'s story writing screen, a child member remarked, "Let's have a story starter button." All of us looked at her and wondered what she meant. She explained that some children may have a difficult time writing stories. For this reason, we should have a way for other children, who do not have problems creating them, to write up the beginnings of stories. This way, if a child is stuck, all she has to do is to push a button and pick from a library of ideas from other kids.

Planets

An adult suggested that we should have a way to name our robotic pet. After all, real pets have names. The children really liked this idea. And then they said we should have planets too. Now, the adults were not quite sure about the purpose of the planets. Since there was no reason NOT to have this feature, we incorporated it into *MyPETS*. We asked the kids why the planets were so important. But they could not explain why they liked the idea.

Several months later, one of the adults had an insight: Our animal does not look like anything from Earth. So it makes sense that it must have come from somewhere among the stars. And, since the robot is an actor, it must have a stage from which to tell its stories. The stage and the origin of the pet were two great reasons to include planets as a feature.

Emotions

Our team was divided into three groups (software, skins and sensors, and skeleton) to design different parts of the robot. The software group was in charge of defining the emotions. Within less than hour of this task, the children members in this group asked the skeleton group what kinds of movements could the robot make. They wanted to know this before they define the action sequences. The skeleton group’s adult member was astounded by this and asked the adult member of the software group whether she had initiated this. No, she said, the children had come up with that insight. Apparently, a couple of days before, they had gone on a field trip to the zoo to study the shapes, movements, and sounds of the animals. They must have realized that physical structures in animals impose a limit in the kinds and range of motions. So the same must be true of the robotic animal they are creating.

Figure 12: A kid member tests an emotion.

Emotion Construction Interface

During $PETS_0$, the adults had created a user interface to control the robot. While it was functionally correct, the kids had no idea how to use it. This became an important design issue for subsequent PETS. Before we asked the kids to invent a new screen, we explored a couple of issues: what did the robot need to know in order to move around, and, how do we give this information to the robot. For example, we knew the robot could move its arms. To do this, it needed to know which arm to move, in what direction, and how far. After the kids understood this relationship, they went ahead and sketched a new interface. Interestingly, not only did they know how to use the controls, so did the adults. This screen, as well as the others within *MyPETS*, reflects a child's approach to controlling technology.

Some Difficulties Of Working With Children Team Members

We did not always have good days. There were times when the team worked together flawlessly. But on other days, there would be pandemonium in our lab. Children sometimes act out. They are after all, still quite young. At times, a kid member would become stubborn. She would refuse to do anything coherent. Or, she would be deliberately destructive. In short, she is having a bad day. This is when the power structure takes a break and the adults become caretakers. We try to resolve the problem if we can. The key is that adult members are both adults and partners. Sometimes, we just have to be the "regular" grownups.

What if the children become bored? We encountered this problem a few times. We believe the main reason is that they are working on the longest-lasting project in a child's experience. It is difficult to hold an adult's attention on a difficult subject; imagine what a child might endure. As a result, we rescheduled our research calendar to include frequent rest and free-play days. These "free sessions" occur during the regular design meetings. But the children did not have to do anything but play with their favorite toys. It is important to schedule regular decompression sessions. But these are not just free play days; they are also great for technology immersion.

What's Different About Our Lab?

The Room

Our laboratory is also our design room. It is full of computers, stuffed animals, bean-bag chairs, lots of sketching material, and lots of stuff made by children. It has a large open central area so that everyone can sit in a circle to chat. We have carpets on our floor, because much of our initial brainstorming occurs with everyone sitting on the ground and throwing out ideas. To the child, it does not feel like a classroom; to the adult, it does not feel like a laboratory. Most importantly, our room is very comfortable and inviting for both adults and children.

Sketches

We sketch a lot. This is the primary way we communicate to each other about our ideas. We write, we draw, we sew, and we build three-dimensional objects. Without sketches, we would not be able to get past the age difference between the child and the adult, and we would have a difficult time communicating with people from different disciplines. We use clay, paper, socks, LEGO blocks, strings, tape, pins, anything we can get our hands on. We try to have as much and as many different kinds of materials in our stock room as possible. You never know what you are going to need to make your ideas come alive.

Figure 13: a sketch in clay of PETS, created by our artist in residence

Mental exercise: Invent a new kind of toy house in your mind. Now, sketch it. (Use any media you like.) Finally, show it to another person. How did you envision this house in your mind? Was it a written descriptions, a drawing, or a three-dimensional object? Next, what did you use to sketch your idea? Did you use more than one medium? Did you prefer one medium to another? Did you find it impossible to convey your vision with some media but trivial with others? Different ideas require different kinds of sketches to convey the message.

Figure 14: an early sketch (2nd of 5) of the arm component

A Typical Session

We meet twice a week. We always start with snack time. Our team sits around a table full of yummy foods, and we chat. We talk about everything except for our design problems. That comes after the snacks. This is an important time. First, children (and grownups too) cannot concentrate if they are hungry. Second, they have just finished their day of regular school, and they need a transition time where they remove their student hats and put on their designer hats. In the real world, these children may still be stuck in the traditional teach-listen model. They need to shed that first before they become our partners.

After snacks, if it is a free day, the children play with anything in our lab. Sometimes they play computer games; other times they design their personal web pages; or, they may videotape each other. (They really like the camcorder.)

If we have a regular research session, then we talk about the major open issues in the project. During our discussions, no one is allowed to raise her hand (like in school), so that the children do not need "permission" to speak out. We discuss what worked from previous sessions and what did not work. We talk about why the ideas failed and what we can do to fix them. Next, we focus on one or two specific things for the day. Here, we trade ideas about technological limits, user interface ideas, the look and feel of the robot, etc. Often, we split into groups to tackle the problem of the day.

Figure 15: The skins and sensors group testing different kinds of covers.

Some people mistakenly believe that designing with children means giving them some very high-level, abstract goal, and then stand back and watch the kids figure out what is needed to achieve it. We do not believe this is a good approach. Consider a farmer and his crop. The farmer prepares the land and plants the seedlings into the soil; he nurtures them by watering them, removing weeds, and fertilizing the soil; then, he stands back and watches his crop grow; finally, he harvests. In our lab, this is the same way we engage our children. We come up with a goal. We explore the motivations for the goal. We think about what is hard and what is easy. This is the first stage, where we prepare and plant the seedlings. In effect, we are providing context for the children so that they understand intuitively the "what" and the "why" behind the project. The next thing we do is to give them the material they need to solve problems. They can sketch any way they like. They can discuss scientific issues with us, etc. Equally important, we correct them, (and they us) when either goes down the wrong path. This is the weeding. Third, we stand back. Now the children have context, they know what they want to build, and, they have the materials to realize their ideas. At the end, we collect our prize.

Cooperative Inquiry

Origins

Over the past several years, our research has involved children as active research partners (Druin et al 1997, Druin et al 1999b). In addition to children, these teams were composed of educators, computer scientists, and artists. Originally, these teams employed methods, such as cooperative design, contextual inquiry, and participatory design, which were designed to facilitate collaboration among adults. While these were adequate starting points, We found that they needed to be modified to account for the inclusion of children as design partners (Druin 1999a). Techniques such as the interview procedures, note-taking practices, etc. evolved to be more suited to child partners. For example, children can draw, rather than write, to express their ideas. These adaptations eventually lead to the development of *cooperative inquiry*, a way to create new technologies for children, with children. It incorporates three complementary design methods: contextual inquiry, participatory design, and technology immersion.

The theoretical basis for cooperative inquiry comes from cooperative design, participatory design, contextual inquiry, activity theory, and situated action. This methodology enable us 1) multidisciplinary partnerships with children, 2) field research that emphasizes understanding context, activities, and artifacts, and 3) iterative low-tech and high-tech prototyping (Druin 1999a).

Contextual Inquiry

In *contextual inquiry*, we ask how processes work, why they are laid out in certain ways, and whether they can be improved. In order to understand a process, researchers should record data within the environment of that process (Beyer & Holtzblatt 1998). We extend this approach by having both adults and children researchers observe and take notes about the child user in her environment. As a result, we collect impressions from both the adult and the child perspectives.

RAW DATA:			DATA ANALYSIS:		
Time	**Quotes**	**Activities**	**Activity Patterns**	**Roles**	**Design Ideas**
10.05	E: Can you draw whatever you want? [Gustav: Yes.] E: (To K) A Christmas Tree? K: Yes!	K. takes the mouse rapidly, draws a red tree, takes the yellow crayon	Drawing	Artist	
		draws something in the corner, rubs out, continues	Drawing Erasing	Artist	
		E. tries to take the mouse	Struggling for control of input device	Leader	Multiple input devices
	E: But I want the long one! E: Noo! [Difficult to erase.] E: There. E: But what's this? [Windows Start menu appears.]	E gets the mouse, tries to get the blue crayon, looks irritated when she cannot get the blue one, gets it	Difficulty selecting tools	Frustrated User	Easier way to select tools

		E. draws a cloud, rubs it out	Drawing Erasing	Artist	
		K. takes the mouse	Struggling for control of input device	Leader	Multiple input devices
		K. goes on with clouds, concentrated	Drawing	Artist	
		E. looks around, yawns		Bored User	

Table 2: portion of a contextual inquiry diagram created by adults

Originally, we asked everyone to record their observations the same way. Table 2 shows an example contextual inquiry diagram. But we soon found that children do not necessarily want to take notes. They prefer to draw cartoons and write captions to describe what they saw. On the other hand, some adults shy away from graphic records, because they do not have confidence in their drawing abilities. In order to accommodate individual differences, we began to ask the children to draw pictures, along with some simple text, to explain their observations (Figures 16 and 17), and adults to use the standard textual method.

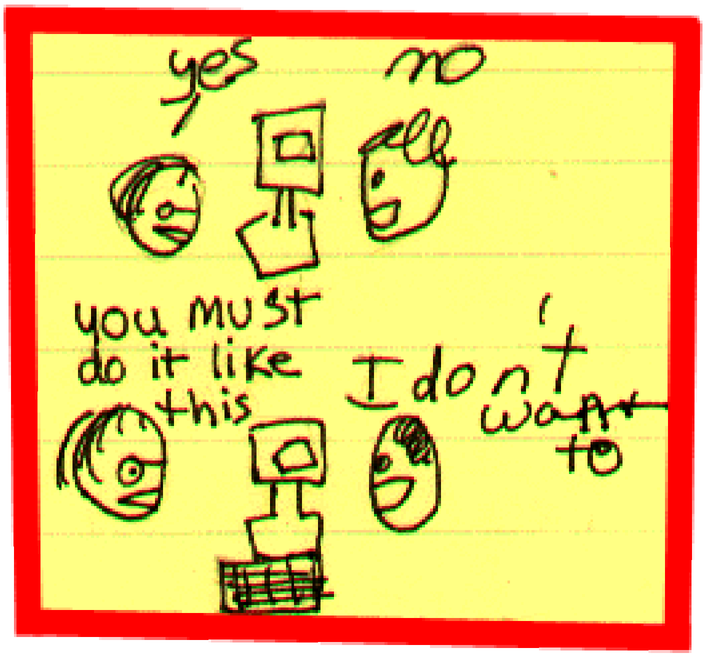

Figure 16: contextual inquiry notes by a kid member observing other kids at a computer

Data we collect through contextual inquiry can provide both the adult and child a common context, or language, for discussion. This is extremely useful when the adult needs to interpret children's comments about the technology. In addition, since we have both textual and graphical data, we can study the similarities and differences between adult and children perceptions about an environment.

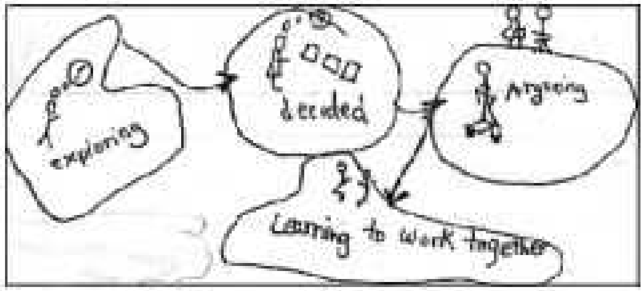

Figure 17: contextual inquiry notes by a 7-year old child

We have found that the most effective textual note taking usually requires a pair of observers, one transcribes the user's quotes, and the other records the concurrent activity. Both people also log the time so that the quotes can be synchronized with their corresponding activities.

A typical observation session includes a pair of observers, an *interactor*, and a child subject in her environment. The interactor's role is to ask questions and initiate discussions about activities. This is an essential role. Without the interactor, children often feel as if they are on-stage and being observed. But by actively engaging them in conversations about what they are doing, children are more likely to reveal their natural patterns. In addition, it is important that the interactor does not take notes, again because children may become self conscious. The interactor is not an interviewer; instead she asks questions that help identify activities or patterns as they occur in the context of the target process. For example, she might ask, "Why are you doing this?" Or, "What's this?" When properly captured by the note takers, the answers to these questions engender both insights about the process and new ideas to improve it.

Interestingly, both adult and child have difficulties being the interactor. Because of her role (such as parent or teacher) in traditional power structure, the adult interactor may steer or direct the child subject. The child interactor's challenge is to remain in the role of the facilitator/observer and not be actively involved in the context being studied.

Contextual inquiry creates a common frame of reference for the adult and child as well as the people with different expertise. An adult can consult and compare the textual records with the graphical notes and understand the meaning behind a child's utterances and behavior. A child can understand the process of "doing research" and become comfortable asking questions and, through her notes, telling others about their impressions.

Participatory Design

Inquiry and Design

Contextual inquiries often generate ideas that can best be understood by construction. We use participatory design to visualize concepts because it balances the power structure between adult and child, and across specialties. These two techniques form an iterative prototyping cycle. Inquiry leads to new ideas, which beget prototypes, which reveal more ideas or flaws, then more prototypes, and so on.

Prototyping

Once we have an idea, we visualize it by using low-tech prototyping. This is a deceivingly simple method, but it can be improperly applied. For example, since our prototyping material is the usual "kid" stuff, such as clay, paper, glue, etc., adults may think that these are solely children's prototyping supplies. Or, if an idea is "mechanical," then the engineer should lead the design effort. Neither is correct.

We use low-tech stuff so that EVERYONE can prototype with them; they are easy to manipulate for both children and adults. Also, choosing the right kinds of material to visualize a specific idea can be tricky. We have observed that a set of supplies that worked in solving a problem was frustrating and limiting to use when we applied them to another. In addition, we have found that creative ideas can come from "non-experts," since making things with low-tech materials do not require special knowledge or tools. Notice that low-tech prototypes do not have to work. They are mainly the manifestations of our mental thoughts. In addition to our notes from contextual inquiry, these objects also become part of our shared experience and knowledge.

Figure 18: Socks filled with tissue paper give the rounded shape of the head.

The insights we gain from low-tech prototyping give us the foundation to build functional high-tech prototypes. Again, we go through the iterative prototyping cycles. But this phase is more deliberate and time consuming. For comparison, Figure 19 shows a shelf full of low-tech prototypes, all built within a few hours; while $PETS_0$, $PETS_1$, and $PETS_2$ required many months of labor. You might wonder whether the few hours of quick prototype are truly useful. Absolutely. Without these simple objects, our team could not communicate the much more abstract requirements of the technology. Furthermore, because they can be built so swiftly, we could create many more trial sketches before deciding on a good design.

Figure 19: some early sketches of "fluffy-fuzzy" robots using low-tech prototype materials and techniques

Learning From Cooperation And Collaboration

Participatory design teaches us how to collaborate with people from different areas and of varying ages. We have noticed that over time, our team members learn to complement each other, so that a person with expertise in one area helps the other people in the group to understand ideas related to that topic. We found this to be a powerful way for us to extend our knowledge. Much of creativity comes from making mental leaps beyond what we understand or novel connections between tidbits that we already know. When we collaborate with a diverse group, someone else inevitably helps us make that jump.

As experts in our fields, we tend to look at problems and solve them within some fixed patterns. While this may be efficient in solving problems in our domain, it can quickly become a hindrance when we are faced with situations that are not quite like anything we have seen. Now, when people with diverse perspectives gather and look at a problem, they each will see a different facet. When one person is stuck and cannot move forward, another, because she perceives the problem differently, offers the mental opening for the first person. Then they move on to the next problem. This happened with such regularity in our group that we realized it was a powerful effect of our methodology.

Here is just one example. When we were moving from $PETS_1$ to $PETS_2$, one of our goals was to design a much stronger but lighter skeleton. Our technologist considered many variations of box-like structures. These designs were strong, to be sure. But they were heavy and required precision machining. There was an additional constraint. He wanted to give as much contact surface as possible so that the “skin,” or foam shell, could attach itself to the hard structure. The extra weight and machining requirements bothered him, until the next design session. Our resident artist was listening to the roboticist describe the physical structure of the robot and his need to build these boxes and how he did not like his solutions. She then said, “I don’t need to glue the foam to the skeleton, because the foam will hold its shape and stay in place around the box.” This was so straightforward and simple, but he just could not see past the box without her help. Now all he had to build was a structure with a top and bottom plate and four columns to support them. Much easier to build and much lighter.

Technology Immersion

From *technology immersion* we understand how things work, why they are good or bad, and how we can make them better. Do we need to invent new technology, or can we reuse current technology in new and novel ways. We call this process the *creation of new metaphors in technology*.

While most adults on our team are surrounded by technology, the same is not true for our children. We believe that in order for them to appreciate fully the impact and meaning of technology in their daily lives, they would need to have access to the best technology and the widest variety that we can afford; and, enough of them so that children do not have to share. In addition to the availability of physical resources, our goal is that they also have enough time to become fully immersed in the technology. An important point: our children decide how and when they use the technology. We do not persuade them to do things "our" way. Otherwise, our inquiry observations would be about the adult's interactions with the environment, not the child's experience.

Design-Centered Learning

Throughout the chapter we have mentioned the different learning experiences that our team encountered. Collaboration, familiarity with technology, and research techniques are just a few of the many enlightening topics. Druin calls the collection of learning outcomes related to cooperative inquiry *designed-centered learning*. Table 3 shows a list of five areas of self-reported designed-centered learning from our team (Druin, research notes, August 1998].

Both adults and children change from the process of building PETS. The adult began as a researcher, perhaps with some biases about the usefulness of elementary school students as partners. Through cooperative inquiry, she begins to learn that every person has a different communication method. And then, as she learns to identify her team members' individual voices and then sharing her knowledge through the appropriate channels, she becomes a partner to the children. Our young members began the project as followers/listeners, because this is the role of the child. With time, she realizes that she has talents too and that she can contribute her knowledge to the group. She also learns how she prefers to communicate her ideas. At this point, she becomes a designer with an equal voice.

(1) I learned about the design process All team members discussed understanding the technology design process in new ways.
(2) I learned respect for my design partners Both adults and children discussed their mutual appreciation for the work that the other could accomplish.
(3) I learned to communicate and collaborate in a team Children and adults discussed the difficulties and the rewards of learning team communication and collaboration skills.
(4) I learned new technology skills and knowledge All team members mentioned technical skills they had come to learn (e.g., building robots and designing software).
(5) I learned new content knowledge In the case of the team working on the PETS project, children and adults discussed learning more about animals.

Table 3: Self-reported design-centered learning

Reflections

We learned so many things from building PETS. Not only did we build a novel robot, but we also learned about working as a group of adults and children as design partners. And now, we close our chapter with some final thoughts.

Transformations

Figure 20: results from a group review session

We learned to become more than adults and children. The computer scientist learned about educational principles; the engineer learned about art; the educator learned about robots; and the artist learned about science. Cooperative inquiry gave us the means to find a common language to share our thoughts and ideas.

Adapt methodology to accommodate both adults and children

We did not abandon a sound methodology (for adults) just because it did not work with children; we adapted and adopted variations of the techniques so that they did apply to the different age groups. But it is important to know when an approach will not work, no matter how you vary it. This is when you abandon it and try something else.

A good team takes time to develop

Our team became a cohesive group after about six months. This is a long time, but well worth the initial investment. In fact, our older kid members began to take on the role of task leaders after about ten months. This level of maturity requires time, and plenty of patience too.

Good thinking comes from being comfortable

Adults might be able to endure a bad design space, but children will not. Make sure your room is comfortable for everyone and that all members feel equal to each other. Our lab is filled with things we make. They remind us of what we have learned and our vision, as a team.

Don't forget to feed your team. You do not want to be in the same room as six hungry and grouchy kids. Snack time also gives everyone enough transition time to mentally join the group.

Know what's out there

Get to know the available construction material. You do not want to spend days making a part when it is available from the local hardware store for pennies. Spend time visiting hardware stores, hobby stores, fabric stores, and electronics stores. Not all technology immersion is high-tech!

Remember the basics

Whenever you encounter a breakdown in communication, check to see if you are still in the cooperative inquiry mode. Did you revert to "plain" adult, or did the child stop being designer?

When you are stuck with a technical design, don't try to solve it yourself. Remember that you are in a team. Bring up the problem during design sessions. Someone on your team just might spark the insight to help you see the answer.

Feed your team

Did we mention this yet?

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