DEVELOPING TECHNOLOGICAL FLUENCY THROUGH CREATIVE ROBOTICS

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Children have frequent access to technologies such as computers, game systems, and mobile phones (Sefton-Green, 2006). But it is useful to distinguish between engaging with technology as a 'consumer' and engaging as a 'creator' or designer (Resnick & Rusk, 1996). Children who engage as the former can use technology efficiently, while those who engage as the latter are creative and adaptive with technology. The question remains of how best to encourage movement along this continuum, towards technological fluency. This study defines three habits of mind associated with fluent technology engagement [(1) approaching technology as a tool and a creative medium, (2) understanding how to engage in a design process, and (3) seeing oneself as competent to engage in technological creativity], and examines the implementation of a learning environment designed to support them. *Robot Diaries,* an out-of-school workshop, encourages middle school girls to explore different ways of expressing and communicating with technology, to integrate technology with personal or fictional storytelling, and to adapt their technical knowledge to suit their own projects and ideas. Two research purposes guide this study. The first is to explore whether *Robot Diaries*, which blends arts and engineering curricula, can support multiple pathways to technological fluency. The second purpose is to develop and test a set of instruments to measure the development of technological fluency.

Robot Diaries was implemented with a group of seven home-schooled girls between the ages of 9 and 14. Instructors from a home school enrichment program ran the workshop. The study utilized a mixed methods approach. Analysis suggests two distinct patterns of engagement in *Robot Diaries* are possible – an engineering focus (characterized by attention to the structure and function of the robot) and an artistic focus (characterized by attention to the robot's representational capacity). The ability to support and sustain multiple levels of participation is an important quality in a workshop designed to broaden engagement in technology exploration activities. Pre-post assessments suggest changes in confidence and (to a lesser extent) knowledge.

This study has implications for the design of learning environments to support technological fluency, and for measuring this construct.

PREFACE

I give my thanks…

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This dissertation is dedicated to the memories of two outstanding individuals:

To my grandfather Israel (Pompa) Bernstein, for inspiring a family legacy of lifelong learning even though his own educational opportunities were cut short.

To Diana Friedman, who (quite literally) started me down this road.

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1.0 INTRODUCTION AND LITERATURE REVIEW

Interviewer: Which were the [technology] items that she uses the most?
Parent: Oh, I would say – well and her cell phone, I [inaudible] the cell phone.
I: Mmm-hmm.
P: Cell phone's a constant. You know, she always has her – is it – I think it's – (raises voice) cell phone in right pocket, iPod in left pocket? Or the other way around?
Daughter: (from another room) No, that's correct
P: Okay, yes.
I: {laugh}
P: Cell phone's in the I- in the right pocket, the iPod's in the left pocket- don't leave home without them, don't go anywhere without them. Except maybe to bed.
D: (from another room) No
P: You take them to bed with you?
D: (from another room) They're just not in my pocket
P: Oh, yeah, but they're in your bedroom with you, yes.
D: No, they're under my pillow

- interview with a parent and her 13 year old daughter

As the above dialogue suggests, technology has become ubiquitous in the lives of many teenagers. Research conducted on out-of-school technology use suggests that even school-aged children have frequent access to technologies such as computers, game systems, and mobile phones (Sefton-Green, 2006).

But what type of engagement do most children experience with technology? Research conducted with a cohort of over 1,000 British children between the ages of 9 and 18 suggests that the most common computer activities in this population include writing and searching the Internet. Each of these activities were reported by over 70% of children, while more creative endeavors such as making websites, animations or films were reported by fewer than 20%[1] (Kent & Facer, 2004).

Were we to characterize the technology engagement of the students interviewed by Kent and Facer (2004), those that primarily engage with their computers using word processing programs or by searching the Internet might fall into the category of technology user or 'consumer' (Resnick & Rusk, 1996). In other words, they are comfortable navigating and utilizing existing technologies, but stop short of creating or designing with it. In comparison, consider the following vignette:

In October of 2005, riots erupted throughout France in response to the deaths of two teenagers who were electrocuted while hiding from police. The incident led Alex Chan, an industrial designer living near Paris, to create a short film entitled *The French Democracy*. The film is 13 minutes long. According to an article in the Washington Post, the creator stated his intentions as follows: "the main intention of this movie is to bring people to think about what really happened in my country by trying to show the starting point and some causes of these riots." The film depicts the negative treatment of ethnic minority citizens in France. Chan created the film using a video game called 'The Movies.' While it is possible to play this game without making original movies, players (such as Chan) sometimes use this tool as a platform for original movie making (BBC, 2005; Lowood, 2008; Musgrove, 2005; Chan's film is available at http://movies.lionhead.com/movie/11520).

Each of these examples demonstrates different uses of consumer technologies. The former shows the type of heavy technology use often associated with adolescents – a cell phone and an iPod within arms reach at all times. The latter example shows a less typical use of consumer technology – as a platform for creating a response to a disturbing community event. Barron's (2006) case studies of technology engagement provide additional examples of children who

[1] Percentages indicate the number of children engaging in each activity 'at least weekly,' and are taken from data collected in 2003. 'Fiddling' with the computer was also reported to be a common activity, with 63% of children reporting this as a weekly activity at home and 56% reporting it at school.

engage with technology in fluent ways, such as the high school student who founded his own company developing web pages for local businesses.

These examples help to form anchor points on a continuum of technology engagement. At one end of the continuum is the non-user of technology. She does not use technology at all, perhaps because she is not comfortable or knowledgeable about technology, or lacks the desire or resources necessary to engage with it[2]. On the other end of the continuum is the fluent technologist. She possesses the knowledge, desire, and resources to create, design, or adapt technology for her own use. In the middle of the continuum is the consumer. She has the knowledge, desire, and resources to utilize technology in different realms (e.g., at school, work, and home), but is either unable or does not desire to expand her engagement beyond consumer use.

The qualitative shift from technology user to technological fluency can be seen largely as a matter of creativity. The consumer is a mundane technology user – she has likely mastered specific technology applications (e.g., the different functions on a cell phone), but tends to use the technology in prescribed ways. The fluent technology user is creative in her technology use, meaning that she is able to use technology in novel and appropriate ways (Amabile, 1996), and thereby able to make technology suit her individual goals in different situations.

The current research takes as a starting point that the shift towards technological fluency is a positive one. This stance is consistent with the general belief that technological literacy and fluency are valuable because they provide the citizenry with the skills needed to participate thoughtfully in a technology-infused society. This includes, but is certainly not limited to, being aware of the benefits and limitations of the technology in our lives, being able to civically

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[2] See Jenkins (2006) for a discussion of the ‘participation gap’ and issues related to technology access.

engage with divisive technology-based societal issues, and feeling comfortable, confident, and 'in control' when encountering technology (National Academy of Engineering, 2002; National Research Council, 1999). The ability to innovate with technology is also believed to be an important factor in the nation's economic success (AAUW, 2000; Schunn, Paulus, Cagan, & Wood, 2006; see also Barley & Orr, 1997).

The goal of the current research is to understand: (1) what is involved in the shift from technology consumer to fluent technologist, and (2) how to facilitate this shift. This dissertation will draw upon existing literature to clarify what is meant by the term 'technological fluency', and to specify the practices and habits of mind associated with fluency. It will then explore how *Robot Diaries,* an out-of-school technology workshop, provides a context for fluent technology engagement for middle school girls.

1.1 TECHNOLOGICAL FLUENCY

Technological fluency has come to be defined as the ability to explore, apply, adapt, or create technology (Baker & O'Neil, 2003; NRC, 1999). The literature offers several specific definitions of this term. For example, Baker and O'Neil suggest that "technological fluency denotes an individual's well-developed skills, propensities, and knowledge that are required to use, design, and develop electronic and bionic hardware and software in order to enhance various aspects of life" (p. 245).

In 1999, the National Research Council published a report entitled, *Being Fluent with Information Technology.* In this report, the committee differentiated between the terms 'literacy' and 'fluency' by explaining that computer literacy, which indicated the presence of skills that enable an individual to use computer applications, was "too modest a goal in the presence of rapid change, because it lacks the necessary 'staying power'" (p. 2). Rather, the committee advocated the development of a technologically fluent citizenry, which would be better able to keep up with the continuous changes in technology. They defined technological fluency as follows:

> People fluent with information technology (FIT persons) are able to express themselves creatively, to reformulate knowledge, and to synthesize new information. Fluency with information technology (i.e., what this report calls FITness) entails a process of lifelong learning in which individuals continually apply what they know to adapt to change and acquire more knowledge to be more effective at applying information technology to their work and personal lives. (p. 2)

The report additionally specifies three types of knowledge associated with fluency: intellectual capabilities (e.g., the ability to engage in reasoning and problem solving), fundamental concepts in information technology (e.g., understanding networks), and contemporary informational technology skills (e.g., setting up a personal computer).

This definition of technological fluency, with its emphasis on the ability to adapt to changing circumstances and the assertion that conceptual understanding is important to enabling adaptation, brings to mind Hatano and Inagaki's (1986) description of adaptive expertise.

Hatano and Inagaki (1986) describe an adaptive expert as one who is able, by virtue of their experience and depth of knowledge, to develop solutions to novel problems. The adaptive expert stands in contrast to the routine expert. While a routine expert can perform procedural skills effectively and efficiently, an adaptive expert also has the conceptual knowledge to understand "the meaning and nature of their object" (p. 263). This underlying conceptual knowledge allows the adaptive expert to be flexible in their application of procedural skills, or to develop new skills and solutions when necessary. Whereas the routine expert is proficient at applying his or her skills to a situation with consistent constraints, the adaptive expert can also succeed in situations presenting new constraints and challenges.

Schwartz, Bransford and Sears (2005) discuss adaptive expertise as a matter of two dimensions: efficiency and innovation. Efficiency refers to the ability to retrieve and execute the appropriate knowledge and skill; innovation is generally associated with a more creative or inventive response. While routine experts are thought to be high on the efficiency scale, adaptive experts are high on both efficiency and innovation (i.e., adaptive experts utilize their knowledge for efficiency but are also able to innovate with it). Importantly, adaptive experts are flexible. As Schwartz et al. note, "innovation often requires a movement *away from* what is momentarily most efficient for the individual or the organization" (p. 30).

A number of parallels can be drawn between Schwartz et al.'s (2005) description of the efficiency and innovation dimensions of adaptive expertise and the fluency continuum. Both notions differentiate individuals who can express skills from those with the capacity to develop new ideas around those skills. In Schwartz et al.'s work, the former group represents routine experts while the latter group represents adaptive experts. The current formulation of the fluency continuum suggests that 'use' may be a type of routine expertise, where an individual has mastered a set of procedural skills and understands when these skills are useful for manipulating technological tools, but lacks the ability to develop non-routine solutions around those technologies. The 'fluent' technologist may be a type of adaptive expert, with the knowledge and capability to develop and apply innovative solutions.

1.2 EDUCATIONAL PATHWAYS TO TECHNOLOGICAL FLUENCY

1.2.1 Multiple Pathways

One response to the society-wide emphasis on the importance of technological fluency has been a proliferation in curricula and out-of-school programming designed to promote related skill sets (see Jenkins, 2006, for sample program snapshots). However, even the briefest look at programs designed to guide students towards a new relationship with technology reveals a remarkable breadth of approaches. A number of these programs focus on the acquisition of engineering and computer programming skills (e.g., Miller & Stein, 2000; Verner, Waks, & Kolberg, 1999), while others facilitate more artistic goals such as personal or creative expression (e.g., Montemayor, Druin, & Hendler, 2000).

One way to make sense of these various approaches is to understand that the architects of each approach may have interpreted the goal differently. In the first approach, students are provided with a depth of engineering knowledge and experience, and asked to apply this knowledge in order to create an effective solution to a task (e.g., expanding a mobile robot system; Verner et al., 1999). If we think about such training as a way to introduce students into an epistemic way of thinking (Shaffer, 2006), we may surmise that these students are being prepared to enter into a community of engineers.

Other approaches seek to engage students in different communities. For example, the Personal Electronic Teller of Stories (PETS) project encourages children to use robotic technology in the service of storytelling (see Montemayor et al., 2000 for a description of the PETS system and the participatory design process that led to it). Locally, a number of workshops have utilized a new panoramic imaging technology called the Gigapan[3] to integrate robotic technology with digital photography. These approaches, which encourage students to place technology in a new context (e.g., storytelling), speak to a more arts-centered approach.

Still other programs purposefully combine these objectives. For example the Cricket and Pico Cricket, which can control motors, lights, and 'music-synthesis devices,' were designed to support artistic expression in addition to supporting lessons in math, science, and engineering (Resnick, 2006; Rusk, Resnick, Berg, & Pezalla-Granlund, 2008). Another example is Artbotics, a university-level course co-taught by computer science and art faculty from the University of Massachusetts-Lowell, along with educational staff from the Revolving Museum, which seeks to combine computer science and art objectives (Kim, Coluntino, Martin, Silka, & Yanco, 2007).

A hybrid approach seems optimal for two reasons. First, fluency with technology often draws on knowledge, skills, and approaches that cross traditional disciplinary boundaries – this is particularly true if we consider contributions like Chan's movie, which was both a technical accomplishment and served a communicative function – making it potentially limiting for educational experiences to define their epistemic approaches too narrowly. Second, students come to these educational experiences with a wide range of interests, and their motivations for engagement may vary as widely as the different roles technology plays in our society. A program that allowed students to participate in a wider range of technology-based activities would be optimal for attracting a more diverse group of students.

The synthesis of disciplinary attributes has been an important part of the development of Robot Diaries, an out-of-school technology community for middle school girls. By combining arts and engineering approaches Robot Diaries enables multiple pathways to technology

[3] See the Gigapan website at http://www.gigapan.org or Eisenberg (2008) for a description.

engagement, allowing students to choose how they want to participate. Unlike programs that narrowly define their pedagogical approach, Robot Diaries leaves room for participants to become comfortable in their approach and explore the technology as a tool for self-expression.

In brief, Robot Diaries engages middle school girls by allowing them to explore different ways of communicating with technology, integrate technology and storytelling, and mobilize and adapt their technology knowledge while designing (and building) their own programmable robots. The robots use a combination of light, sound, and movement to tell stories, express emotions, make statements, or otherwise engage in narrative. A networking site allows workshop participants to share their robot programs with other members of the group.

The Robot Diaries program was developed in accordance with principles drawn from the literatures on engineering and art education and practice. Specifically, the workshop aims to move participants towards fluent technology engagement. Specific goals for the workshop include helping students:

- Approach technology as a tool and a creative medium
- Understand how to engage in a design process;
- See themselves as competent to engage in acts of technological creativity

1.2.2 Encouraging the Practice of Fluent Technology Engagement

1.2.2.1 Design is Essential.

Following a cue from the science education literature (National Research Council, 2007), we have taken the approach that the most effective way to introduce girls to the idea of fluent technology engagement is to involve them in the essential practice of the community. In this case, that practice is design.

Thinking about the example provided above, design is one way in which Chan's actions differed from those of many video game players – he chose to become a creator by using the game to initiate the design process that produced his film. Here, it is the presence of a design process that differentiates consumer technology use (e.g., playing a video game) from creative engagement (e.g., using the game as a platform to respond to a community event). This should not be surprising if we recall that creativity is a fundamental characteristic underlying the shift from technology consumer to fluent user, and as Lawson (2006) reminds us, design is "one of the most creative of human pursuits" (p. 145).

In fact, design has been described as an important practice in a number of generative and creative communities (e.g., see Lawson, 2006, for a description of the design process in architecture, and Heylighen & Neuckermans, 1999, for the importance of design in architecture education; see Bucciarelli, 1994, for an example of the engineering design process; see Mace & Ward, 2002, for a description of the creative process in art). In his book *The Reflective Practitioner,* Schon (1983) describes design as a "conversation with the materials of a situation" (p. 78). He elaborates by explaining that the designer "shapes the situation, in accordance with his initial appreciation of it, the situation 'talks back', and then he responds to the situation's back-talk" (p. 79). Through this process of 'conversation', the designer is able to try out different ideas and understand new features of the design situation as they emerge through an iterative process.

1.2.2.2 Design as Pedagogy.

The design process carries its own educational benefits, such as the ability to engage in ill-structured (real world) problem solving and practice critical thinking skills (Cross, 1982). As such, there is a rich history of design as educational pedagogy in a number of disciplines, most notably science and technology (see, for example, Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005; Hmelo, Holton, & Kolodner, 2000; Liu & Hsiao, 2002; Mehalik, Doppelt, & Schunn, 2008; Sadler, Coyle, & Schwartz, 2000). Kolodner and colleagues have implemented a series of classroom interventions as part of the 'Learning by Design' project (Kolodner et al., 2003). These lessons promote science learning by engaging students in design challenges around specific areas of scientific content. For example, Puntambekar & Kolodner (2005) engaged students in a design challenge that required them to develop plans for preventing soil erosion on an island. Learning through design has been shown to be an effective means of enhancing science learning, particularly when compared with other instructional approaches (e.g., direct instruction or scripted inquiry; Hmelo et al.; Mehalik et al.).

However, there are subtle differences between the design approaches enacted in the science education literature and the Robot Diaries approach. One difference is that while scientific design challenges often utilize an engineering design method, Robot Diaries explores a hybrid design approach, consistent with the belief that fluent technology engagement does not sit solely within an engineering sphere (see Barley & Orr, 1997). Rather, the creation of novel technologies is akin to engineering in that it involves building an entity (either physical or virtual), but as the Chan vignette above suggests, the purpose of the building activity might be to express a message or aesthetic, a goal that is more akin to art.

With regard to design, there are subtle differences in the practices of the artistic and engineering communities[4] (see Mitcham, 1994). While most creative processes can be assumed to share the basic elements of idea generation and exploration (Finke, Ward, & Smith, 1992), the engineering design process often focuses on functionality as a primary outcome (Cropley &

[4] I am indebted to Carl DiSalvo for pointing out the distinctions between artistic and engineering design.

Cropley, 2005; or as one engineering ethnographer put it, "looks are secondary; function is primary," Bucciarelli, 1994, p. 1). In contrast, aesthetics and expression are legitimate goals of an artistic design process (Mace & Ward, 2002; Wachowiak & Clements, 1997).

One consequence of this difference is the criteria by which the resulting products are judged. Cropley and Cropley (2005) suggest the following four criteria for judging the creativity of engineered products: relevance/effectiveness (i.e., does the product solve the problem?), novelty, elegance (i.e., the product is "pleasing"), and generalizability (i.e., can the product be applied elsewhere?). This criteria will yield an understanding of the product's form, function, and future function as related to the class of tasks or problems the product was designed to address.

When a group of artists were asked to define the characteristics of a creative product, functionality was included in their list of characteristics[5], as were originality, and a factor termed 'impression' which "refers to the view of others who are confronted with the creative product," and suggests characteristics such as aesthetics, understandability, and logic (Gluck, Ernst, & Unger, 2002, p. 59).[6]

In light of these differences the Robot Diaries curriculum presents a hybrid design approach, which encourages functionality considerations within the context of an expressive goal.

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[5] Although this was more the case for artists who worked in constrained domains, such as architects and graphic designers, than those who worked in unconstrained domains, such painters, sculptors, and metal designers (Gluck et al., 2002).

[6] However, it should be noted that agreement on these characteristics was generally low, particularly for the artists who worked in relatively 'free' (i.e., unconstrained) environments, such as painters, sculptors, and metal workers (Gluck et al.). Perhaps this is why some creativity researchers have encouraged the use of purely subjective criteria for evaluations of creativity (see, for example, Amabile, 1996 and Hennessey, 1994, for a description of the consensual assessment technique).

1.3 HABITS OF MIND FOR CREATIVE TECHNOLOGY ENGAGEMENT

In addition to promoting engagement in the design process, Robot Diaries also seeks to promote those skills or dispositions that underlie the ability to engage in design. Thus, we have turned again to the engineering and art literatures to help shape our educational objectives.

In his writings on what it means to ‘think mathematically,’ Schoenfeld observed that, “being trained in the use of [the tools of mathematics] no more means that one thinks mathematically than knowing how to use shop tools makes one a craftsperson” (1994, p. 60). One way to interpret this statement is to understand that in mathematics, as in many domains, mastering only the tools associated with the domain does not make one a competent practitioner. Rather, Schoenfeld’s (1991, 1992, 1994) description of what it means to ‘think mathematically’ includes the adoption of certain values and predilections, as well as the development of competencies. The AAAS (2007) has identified the skills, values, and attitudes that underlie disciplinary engagement as ‘habits of mind.’

In order to understand how creative technology use might call upon the values, skills, knowledge (both contextual and scientific), and attitudes of engineering and art, we ask the following questions of each domain:

- What values do they bring to design?
- What knowledge and skills do they bring to design projects?
- What resources do they engage during design projects?

Our goal in asking these questions is to understand how we might develop an experience that calls upon the fundamental habits of mind in both engineering and art. We will also keep in mind the point made by Barley and Orr (1997), that technology work blends aspects of science and craft. This point becomes relevant in thinking about the knowledge and skills expressed in the practice of technology work – both the formalized knowledge associated with science, and the contextual knowledge associated with craft, are relevant contributors (also see Faulkner's [1994] discussion of the distinctions between science and technology).

1.3.1 What values do they bring to design?

In his ethnography of engineering firms, Bucciarelli (1994) observes that engineers work within an 'object world.' This object world is centered around an artifact (e.g., a piece of hardware) but also includes elements associated with that artifact, such as related theories, skills, and techniques. Work within the object world is goal-oriented, and often reflects the value placed on functionality and efficiency (Bucciarelli; Cropley & Cropley, 2005). The National Academy of Engineering publication *Technically Speaking* defines engineering design as a process of "starting with a set of criteria and constraints and working towards a solution – a device, say, or a process – that meets those conditions" (p. 13). This definition, which focuses on movement towards an appropriate solution, reinforces the values of efficiency and functionality.

In contrast, work on arts projects may take a more exploratory form. In their case study of an artist schooled in Chinese ink painting, Yokochi and Okada (2005) report that the artist's global image for each painting was largely developed as he painted (anecdotal reports of a similar process can be found in Candy & Edmonds, 2002; see also Mace & Ward, 2002). While the engineer's approach is consistent with what Candy and Edmonds define as a 'technology-led' ethic, the artists' process may be more sensitive to what they call an 'art-led' ethic, in which the focus is on "the importance of audience awareness or personal engagement" (p. 58), rather than achieving a specific goal. Mace and Ward additionally (2002) explain that in choosing ideas, "artists tend to select those ideas that are experientially based and personally close to them or those that relate to and further their existing body of work" (p. 184).

1.3.2 What knowledge and skills do they bring to design projects?

By all accounts, engineers bring considerable knowledge and skills to design projects. Depending on the particulars of a project, this may include theoretical knowledge drawn from specific scientific disciplines (e.g., Alexander Graham Bell relied heavily on his knowledge of speech and acoustics in the development of the telephone; Carlson & Gorman, 1992), as well as knowledge of mathematics, properties of materials, and the behavior of systems (Bucciarelli, 1994; Faulkner, 1994; see Verner et al., 1999, for sample curricula). The ability to engage in reasoning processes common to the practice of engineering, such as analogical reasoning (Christensen & Schunn, 2007; Visser, 1996), may also be seen as part of this skill set.

Another major component of the engineering knowledge base is knowledge related to the design process (Ahmed, 2005; Faulkner, 1994). Skills related to successful engagement with the design process include the ability to form problem representations (i.e., an understanding of the goals and constraints of the design task; Malhotra, Thomas, Carroll, & Miller, 1980; Simon, 1995), the ability to generate and explore potential solutions (Finke et al., 1992), and the ability to evaluate solution options (Stempfle & Badke-Schaub, 2002). Evaluation and solution decisions often proceed via a method of satisficing, i.e., accepting a solution that is "good enough" in lieu of engaging in a systematic search for an optimal solution (Ball, Evans & Dennis, 1994; Simon, 1981).

Knowledgeable and experienced engineers generally engage with the design process in different ways than novices (Bernstein, 2007). Lab studies of engineering design tasks suggest that experienced designers are able to infer design constraints from a task (Chevalier & Ivory, 2003), and are able to organize their design efforts even when presented with an ill-structured problem (Fricke, 1996).

Certain patterns of solution generation and exploration seem to be more common in experienced engineers. For example, it is sometimes more common for experts to develop solution ideas in a ‘breadth-first’ pattern, where multiple parts of a design solution are considered in parallel. This strategy contrasts with that used by novices who may try to generate solutions for one problem area at a time (Ball, et al., 1994; Ball, Evans, Dennis & Ormerod, 1997; Crismond, 2001; Fricke, 1996; Kim, Kim, Lee & Park, 2007; although see Visser, 2006, for an alternative point of view). Experienced designers have also been found to spend more time exploring their solution ideas prior to implementing them (Ahmed, Wallace & Blessing, 2003).

While scientific and design knowledge are important to the engineering design process, contextual knowledge may also play a role. In her review of knowledge used during technological innovation, Faulkner (1994) identified five relevant types: knowledge related to the natural world, knowledge related to design practice, knowledge related to experimental R&D, knowledge related to the final product, and knowledge related to knowledge. Knowledge of the ‘final product’ seems to imply local and contextual knowledge. She described this knowledge category as containing three parts – knowledge of ‘operating performance’ (gathered via pilot use), knowledge related to the ‘performance of components and materials,’ and ‘production competence’ (p. 448-449). Bucciarelli’s work also suggests the importance of local knowledge (i.e., what are the tolerances of this particular instrument?) in completing engineering tasks.

The knowledge and skills exhibited by engineers are similar to those described in the ITEA's *Standards for Technological Literacy* (2002). These standards emphasize the development of 'core concepts' associated with technology, such as an understanding of systems, controls, optimization and trade-offs, as well as engineering design process skills such as the ability to work within a set of constraints.

As in engineering, the knowledge base related to artistic practice is deep and varied. Contemporary art education focuses on a broad range of knowledge, skills, and habits of mind, including knowledge and abilities associated with aesthetic judgments, art criticism, art history, and art production/studio work (Hetland, Winner, Veenema, & Sheridan, 2007; PA Department of Education, 2002; Wachowiak & Clements, 1997).

Engaging in artistic practice (both production and criticism/judgment) requires an understanding of the fundamental elements and principles for that medium. In the visual arts, basic elements include color, line, form/shape, space, texture/pattern, and value; principles include balance, contrast, movement/rhythm, proportion/scale, repetition, emphasis, unity (PA Department of Education, 2002; Wachowiak & Clements, 1997). Understanding an element, for example color, might include acquiring relevant vocabulary (hue, value, intensity), being able to use color in artistic production (e.g., understanding how colors relate to one another or using a color wheel), and being able to comment on how color impacts the aesthetic of a work (Wachowiak & Clements, 1997). Artistic practice also engages a number of thinking skills such as analogy, metaphor, abstract reasoning, and problem solving (Mace & Ward, 2002; Okada, Yokochi, Ishibashi, Namba, & Ueda, 2007).

Like engineering design, a large body of knowledge surrounds artistic production. Hetland et al. (2007) have suggested eight of habits of mind associated with visual arts production: developing craft (i.e., techniques for working with various tools/materials and an understanding of how/when to use them), learning to envision (i.e., imagining what a piece of work will look like and developing a production plan), learning to express (i.e., conveying intangible properties, such as mood, in one's work), learning to observe/see the artistic elements in a work, learning to reflect or be metacognitive about one's own process, learning to stretch and explore (and experiment), engagement and persistence, and learning to understand the artist's worlds (i.e., understanding how to interact with the broader art community).

This brief review suggests some overlap between engineering and artistic knowledge, such as in the understanding and use of varied materials as well as mastery of a body of principled knowledge. However, differences exist in engagement with the creative process, and in the emphasis on context and critique.

1.3.3 What resources do they engage during design projects?

Both engineers and artists engage social and personal resources in their work. Descriptions of engineering work often include reference to the skillful use of a wider network of expertise and material resources (e.g., Bradshaw, 2005). Faulkner's (1994) review suggests that 'knowledge related to knowledge' (i.e., knowing how to find needed materials or information) is important for innovation. Candy and Edmonds (Candy & Edmonds, 2002; Edmonds et al., 2005) describe the extensive collaborations that occurred between artists and technologists working on digital art projects. Bell (NRC, 2006) describes the social practices associated with technological fluency as a form of distributed expertise (see also Jenkins, 2006).

Design work also involves the application of considerable personal resources. As Amabile (1996) reminds us, internal motivation is an essential element of creative production.

Mace and Ward (2002) indicate that an artist's interests are often a driving force behind the design of a particular work, lending credence to the belief that personal interest is a significant part of creative technology work. Interest and identity have both been posited as significant factors impacting science learning (see Falk, 2006; Falk & Storksdieck, 2005) and professional practice (see Eberbach & Crowley, 2009) as well.

1.3.4 Habits of Mind forwarded in Robot Diaries

In summary, our review of the engineering and art education and practice literatures help us shape our understanding of three habits of mind that might be promoted within the Robot Diaries workshops.

1.3.4.1 Approach technology as a tool and a creative medium.

This habit of mind is meant to combine the engineering and artistic points of view on technology, by encouraging participants to understand that applications of technology are flexible and (potentially) unlimited. Robot Diaries facilitates this belief about technology by encouraging participants to see technology's creative potential in two different domains – art and engineering. This habit of mind is representative of an attitude or set of beliefs about technology. Individuals who hold this belief understand that technology can be mobilized towards a wide range of goals, including their own (personal) goals.

1.3.4.2 Understand how to engage in a design process.

Both artists and engineers engage in a design process, although some of the parameters of the process may differ. This review identifies numerous points of similarity (i.e., the generation and evaluation of design ideas), and two potential points of divergence – the nature of the design goal (expressive or functional), and the criteria by which the resulting product will be judged.

Robot Diaries promotes engagement in a design process that adopts much of the rigor of engineering design. Participants are explicitly taught the steps in a design process (planning – prototyping – testing – evaluating – documenting), and are provided with guidance as they move through the process. However, the design process enacted in Robot Diaries maintains an artistic goal and judgment criteria – the robots are meant to communicate, and participants will be given opportunities to revise their robots designs based upon this criteria.

1.3.4.3 See one's self as competent to engage in acts of technological creativity.

Research suggests differences between boys' and girls' levels of confidence to engage in fluency-building activities – girls, particularly those with little experience in this area, appear to have lower levels of confidence than do boys with similar experiences; similar differences were found with regard to levels of interest (Barron, 2004). The Robot Diaries curriculum seeks to enhance girls' confidence in their abilities to engage in creative technology work by creating a supportive, non-competitive atmosphere for technology exploration. We also seek to increase girls' interest in this type of work by providing goals and activities that are interesting and relevant to this demographic (Edelson & Joseph, 2004).

1.4 RESEARCH GOALS

This dissertation explores the development of technological fluency (as indexed by the three habits of mind described above) in the context of Robot Diaries, an out-of-school learning environment. The study proposes to further our understanding of technological fluency in two ways.

First, this study will explore the different ways that students can move towards technological fluency. As a hybrid curriculum, Robot Diaries is designed to support both arts- and engineering-based approaches to technology exploration. Thus, one goal of this study is to test the hypothesis that multiple pathways to fluency are possible within this learning environment. The guiding question for this strand of the research is as follows: Can we identify distinct patterns of workshop engagement and movement towards fluency, by studying participants' expression of the three habits of mind? Based upon the curriculum, two patterns of engagement – that of an engineer and that of an artist – may be possible. This research question necessitates an exploratory stance, best supported by a qualitative methodology.

The second purpose for this study is to develop and test a set of instruments designed to measure the development of technological fluency. The guiding question for this strand of the research is: Can we develop assessment tools that accurately measure the development of technological fluency in a context like Robot Diaries? This research goal invites a quantitative, pre-post assessment approach.

The next chapter (Chapter 2) describes the Robot Diaries workshop and research methodology in greater detail. Chapter 3 addresses the first research purpose by presenting a qualitative analysis of two learners' participation in Robot Diaries. Chapter 4 addresses the second research purpose by describing the pre-post measurement tools and presenting results from the quantitative analysis. Chapter 5 presents a synthesis of these two research approaches, as well as lessons learned about conceptualizing and measuring technological fluency.

2.0 RESEARCH CONTEXT AND METHODS

2.1 RESEARCH CONTEXT

The Robot Diaries project[7] was founded in 2006, with the goal of encouraging girls' participation in creative technology exploration and use. Research suggests that out-of-school resources are an important point of access for technology learning (Barron, 2004). However, pilot work with middle school girls and their parents suggested that for those who were interested in exploring technology, existing opportunities such as LEGO League competitions were unappealing and potentially intimidating (Hamner, Lauwers, Bernstein, Nourbakhsh, & DiSalvo, 2008). Robot Diaries was developed to provide an alternative to existing technology programming for this population.

As a technology community for middle school girls, Robot Diaries encourages participants to *explore* different ways of expressing and communicating with technology, and to *integrate* technology with personal or fictional storytelling. These goals direct the girls' efforts as they design and build their own robots, a task that gives them the opportunity to mobilize and *adapt* technical knowledge as needed to suit their projects and ideas. The workshop's focus on

[7] The Robot Diaries project is a collaboration between the University of Pittsburgh Center for Learning in Out-of-School Environments (UPCLOSE) and the Community Robotics Education and Technology Empowerment (CREATE) Lab at Carnegie Mellon University. Robot Diaries team members include Emily Hamner, Tom Lauwers, Kristen Stubbs, Carl DiSalvo, and the author.

emotional expression and storytelling is the result of a series of participatory design activities with middle school girls (Hamner, Lauwers, Bernstein, Stubbs, et al., 2008). Through these activities we developed an understanding of the girls' existing interests, and "established relevance" by tying these interests to the technology activities (Edelson & Joseph, 2004).

The infrastructure of the Robot Diaries community is designed to support girls' exploration and integration of technology and storytelling. The robots they build communicate (rather than compete) with other participants, both directly via storytelling games (e.g., charades and Mad Libs) and at a distance via the community's messaging site (participants can send messages and share programs with each other on the site). These activities also serve as opportunities for the girls to collect feedback on their robot designs and to make changes to improve their robots' communication abilities. It is through the process of designing, building, and improving their designs that participants can adapt their technical knowledge in service of individual building goals. These activities also allow the girls to work together to foster a supportive and cooperative environment.

This focus on individual design and iteration sets the current workshop apart from previous multi-week Robot Diaries workshops. The first such workshop took place in the summer of 2006 and ran for approximately 12 contact hours. The second workshop took place during the fall of 2006, and ran for approximately 18 contact hours. The primary goal of these first two workshops, as well as many other short-term outreach programs conducted during this time, was to develop the parameters for a creative technology community and a platform for technology exploration that would be appropriate for this participant demographic. (See Hamner, Lauwers, Bernstein, Stubbs, et al., 2008 for details regarding the progression of the Robot Diaries curriculum). An evaluation of the 2006 workshop suggested gains in participants' declarative knowledge about technology, and gains in their ability to describe technological systems. Anecdotal evidence from parents of workshop participants suggested positive changes for some participants with respect to their comfort/confidence, interest, and engagement with technology, and a broadening of perspective about technology (see Hamner, Lauwers, Bernstein, Nourbakhsh, et al, 2008; Hamner, Lauwers, Bernstein, Stubbs, et al., 2008).

2.1.1 Curriculum Details

The current Robot Diaries curriculum runs for16 contact hours over a period of several weeks. During Part 1 (four contact hours), students first introduced to the concept of using robots to express emotions by viewing several examples of robotic art. Students are also introduced to the relevant hardware and software. The primary piece of hardware is the hummingbird, a microcontroller that was specifically designed to accompany this curriculum[8]. The hummingbird contains ports for plugging in motors (including vibration motors), sensors, servos (a type of actuator), a speaker, 2 different types of LED's (light-emitting diodes), and connects to a computer via a USB cable. Students also learn how to use the components listed above, and are introduced to the custom software and programming interface developed to accompany the hummingbird. The main activities in this part of the curriculum are an expressive charades game (an improvisational activity that uses stage props but no technology), a circuit-building task, and a design challenge where participants use the hardware and software to create sound effects for a movie clip. Students are also given a homework assignment where they are asked to identify different technology components (e.g., LED's, motors) in their homes.

[8] The hummingbird was designed by Tom Lauwers of the CREATE lab. [See Hamner, Lauwers, Bernstein, Stubbs et al., 2008 for technical details]

During part 2 of the curriculum (four contact hours), students are introduced to the design process, develop individual websites, and sketch out and build their own robots. After an initial robot building session, the group engages in a show and tell/critique and plays an expressive game (e.g., charades) with the robots. At this point in the workshop, students begin taking their robots home after every session, and are encouraged to continue using and programming their robots outside of the workshop. To facilitate this behavior, students are given a homework assignment that encourages them to program stories or emotional expressions on their robots and share their programs with other workshop participants. (The suite of custom software applications designed for this project includes a messaging client, where participants can send public and private messages to other community members and share their robot programs).

The main focus of part 3 of the curriculum (eight contact hours) is design iteration. While students were given a limited number of components for their robot during the initial building session, they are now given additional components and encouraged to modify their robots based on feedback received from the show and tell and expressive games. Students go through two full iterative cycles of using their robot in an expressive capacity (e.g., playing an expressive game like robot charades or Mad Libs), reflecting on their current design, and implementing changes to their robots. The final few hours of this section of the curriculum are devoted to producing a play (a group activity), which is performed for friends and family at the conclusion of the workshop.

2.2 METHOD

2.2.1 Participants

The Robot Diaries workshop was run as part of a Home School enrichment program. The enrichment program drew students from a mid-sized urban area and the surrounding suburban and rural communities. Seven female homeschooling students participated in the workshop. All participants were between the ages of 9 and 14. Two of the participants were sisters. Participants were recruited by the workshop instructors.

2.2.2 Materials

2.2.2.1 Child pre interview.

Child pre-interviews contained three sets of questions. First, participants were asked to provide background information about themselves (e.g., what types of things they liked to do). The remaining interview questions addressed participants' recognition of creative and expressive uses of technology (e.g., ideas about repurposing a familiar technology), and their technical content knowledge (e.g., ability to describe a simple technological system). Participants were asked to build a model of a new technology as part of the interview. They also completed three written surveys assessing confidence, interest, and the extent of their prior technology experience. Chapter 4 describes each measure in greater detail (see also Appendix A). Each child pre interview took between 60 and 90 minutes to complete.

2.2.2.2 Child mid-point interview.

Midpoint interview questions included confidence assessments (e.g., what have you felt most/least confidence doing in the workshop thus far?), inquiries about the robot building process (e.g., last week you made some changes to your robot, what did you change and why?), and follow-up questions from workshop-related activities (e.g., I saw on the messenger that some of your family made programs for your robot. Can you tell me more about that?). A subset of these interview questions was tailored for each child.

2.2.2.3 Child post interview.

The child post interview included all of the questions from the pre interview. In addition, each child was asked to describe and answer questions about her robot (e.g., what is your favorite thing about your robot? How does your robot work?). A subset of these questions was tailored for each child, based upon the researcher's observations during the workshop and her examination of the child's design notebook. For example, if there were elements in a design sketch that were never realized in the physical robot, the participant was asked to explain why she did not build those features. Children were also asked about their experience producing the play, and about their overall workshop experience. See Appendix B for a sample interview protocol.

2.2.2.4 Child debugging task (post only).

Each child participated in a debugging task. This task was designed to assess participants' ability to identify and solve problems with the hardware and software they learned to use during the workshop. The assessment was conducted with each student individually.

At the start of the task children were presented with a complete but malfunctioning robot, a program written for the robot, a screwdriver, a set of spare parts, and an informational handout from the workshop. They were shown a video of the robot performing a 4-step sequence, and asked to modify the robot as necessary to make it imitate the video. To successfully debug the robot, participants had to solve five problems with the robot's hardware or accompanying program: (1) the processor board was turned off, (2) two LED's were unplugged from the processor board, (3) a vibration motor was plugged in to a different port than the one called up in the program, (4) there was an error in the program, and (5) one LED was broken and in need of replacement. Participants were given 25 minutes to complete this task. See Hamner, Lauwers, & Bernstein (2010) for additional details.

2.2.2.5 Parent pre interview.

Parents were interviewed either prior to, or during the first week of the workshop. All parent interviewees were female. The purpose of the parent pre-interview was to acquire information about the family's interest in technology, and the way technology is generally thought of in the home (e.g., is technology an 'unwelcome guest' in the home, or is the family comfortable with technology). Parents were also asked about their child's prior technology-related activities and knowledge and her art-related activities, as a supplement to the information provided by the participant herself. See Appendix C for sample questions.

2.2.2.6 Parent mid-point interview.

A brief mid-point interview was conducted with each parent at the time of the child midpoint-interviews. These interviews included questions about the parents' overall impressions of the workshop, and the impact of the workshop on family life (e.g., has your daughter talked to you about the workshop?). A subset of parent interview questions was tailored for each participant, to allow for follow-up on previous conversations.

2.2.2.7 Parent post interview.

During the post-workshop interviews parents were asked to reflect on their daughters' participation in the workshop, specifically if they noticed any changes in their child's comfort or interest with respect to technology. Parents were also asked to report on any workshop-related activities conducted at home. See Appendix D for sample questions.

2.2.2.8 Design journals.

Participants were asked to record information about their robot design process in a journal. This journal was paper-based at the start of the workshop. Towards the end of the workshop, participants had the option of making journal entries on their websites. The design journals contained two types of entries – sketches and reflections. Participants completed three sketches (one during each of the main robot building/rebuilding sessions) and five reflections. Sample reflection questions include:

- What changes did you make to your robot today?
- Why did you make those changes? Were any of these changes the result of something you learned while using your robot? If so, what?
- What was the biggest challenge you faced in redesigning your robot today and how did you solve it?
- Based on your experience playing [a particular game in the workshop], do you think your robot is more expressive now than it was before? How?

2.2.2.9 Video journals.

During the second workshop session, participants were given small, easy-to use video cameras for home use. The girls were instructed to use these cameras to record any activities with their robots that occur outside of the workshop (e.g., interesting programs created at home, robot demonstrations, etc.). Upon receiving the cameras, participants were also asked to shoot a video that showed where the robot would be located in their home.

2.2.2.10 Instructor interviews.

Over the course of the workshop, the researcher conducted two informal interviews with each workshop instructor (see below). The purpose of these interviews was to understand, from the instructors' point of view, how the students were progressing and interacting with the curriculum.

2.2.3 Design and Procedure

Robot Diaries workshop sessions were held once a week over a period of six weeks, with an additional session added at the end of the workshop to enable participants' families to view their robots and the play. The workshop met for approximately 16 contact hours during the 6-week period.[9] Two instructors from the home school enrichment program (mothers of home school children) led the workshop. These instructors received approximately 10 hours of training on the

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[9] As written, the Robot Diaries curriculum is divided into three parts: parts one and two include two 2-hour sessions each, and part three (design iteration) includes four 2-hour sessions, for a total of eight 2-hour sessions (16 contact hours). The home school group ran the curriculum in six weeks. They ran the two sessions in parts 1 and 2 of the curriculum during one extended session. Part 3 of the curriculum was run as written, in four 2-hour segments. A copy of the curriculum (which is now called *Arts and Bots*) can be downloaded here: http://www.andrew.cmu.edu/~etf/RobotDiariesCurriculum-July18,2008.zip

Robot Diaries technology and curriculum. Both instructors had previously taught arts and crafts classes through the home school enrichment program, though neither had taught a technology-intensive course before. At least one member of the Robot Diaries curriculum team was also present at each workshop session to provide technical assistance and/or curriculum support as needed.

In addition to the Robot Diaries curriculum team member, a researcher (the author) attended each workshop session. The researcher operated the video cameras and took detailed field notes. The curriculum team member also took field notes during each session. These field notes serve as a record of the instruction provided during the workshop, participants' reactions to the curriculum and materials, and the overall tenor of the workshop on a particular day.

All workshop sessions took place in the home of one of the instructors, in a space normally used for homeschooling activities. Each instructor had a daughter participating in the workshop.

Parent and participant pre interviews took place prior to the start of the first workshop session (or in the case of some parent interviews, during the first week of the workshop). Midpoint interviews occurred after the 3rd or 4th workshop session. Post interviews took place after the final workshop session was completed. The debugging task took place either during the final workshop session, or as part of the post interview. Child pre and post workshop assessments took place in person. Mid-point child interviews were conducted via telephone. Parent interviews were conducted either in-person or via telephone.

The researcher collected participants' design journals at the conclusion of the workshop. These journals were photocopied, and the originals were returned to the participants.

Participants were permitted to keep their robots at the end of the workshop, so extensive photographs were taken during each workshop session.

3.0 IN-DEPTH ANALYSIS OF TWO LEARNERS

One of the goals of this study is to understand how the Robot Diaries learning environment supported (or did not support) the development of technological fluency. The next two chapters will present an analysis of participants' responses to Robot Diaries. The current chapter provides an in-depth account of two learners' experiences in the Robot Diaries workshop. Chapter 4 will present an analysis of pre-post measures.

3.1 PATTERNS OF THINKING

We can begin this analysis by asking two questions about Robot Diaries: (1) what patterns of thinking do we see in this learning environment, and (2) what speculations can we make about how these patterns were facilitated (Cobb et al., 2003).

In the case of Robot Diaries, we are interested in patterns of thinking that reflect the development of technological fluency. In chapter 1, I argued that we could index fluency development via the presence of three habits of mind:

- Approaching technology as a tool and as a creative medium
- Understanding how to engage in a design process.
- Seeing one's self as competent to engage in acts of technological creativity.

There are many ways to engage with technology inside of a creative community. It is thereby difficult to think about each of the habits of mind as representing a single pattern of responses. A priori, we can identify at least two patterns of responses – the first prototypical of an engineer, and the second prototypical of an artist. *In this chapter, I will argue that the Robot Diaries approach to technology engagement, which emphasizes expressive uses of technology and a multi-disciplinary (arts and engineering) design curriculum, is sufficiently flexible to enable these divergent patterns of engagement with technology.* Indeed, this flexibility is one of the major strengths of the Robot Diaries approach to promoting technological fluency.

Within the context of a Robot Diaries workshop, these two prototypes may play out in the following way:

> *The "Engineer"* is concerned mainly with the robot, its structure and function. In describing her expectations for her robot, the Engineer talks about building a robot that meets her performance goals (i.e., the robot can move in a certain way, or get certain things done). Her design process may be characterized by planning – she likely sketches out the day's goals and adheres to those plans while working on her robot. She expresses creativity in a technical way, often by adapting the technology to meet her goals. She expresses confidence in her ability to handle the technical aspects of the project. When design failures occur, she can recover from them because she has the knowledge and confidence to redefine the problem and try out different solutions.
>
> *The "Artist"* is concerned mainly with aesthetic aspects of the robot. In describing her expectations for her robot, the Artist expresses her goals with respect to the robot's form/visual aspects of the robot (e.g., what it looks like, what 'image' it puts forth). Her robot stands for something – it is a representation, either of the creator herself or of a made-up character. The artist expresses her creativity through this representative form – she puts time into figuring out how people will interpret her robot, and comes up with creative ways of allowing the robot to 'speak'. She is confident in her ability to use her robot expressively.

Using these two patterns as a guide, this chapter will present an in-depth exploration of two girls' participation in Robot Diaries. I will argue that the two girls – Allison and Dakota[10] – each demonstrate a different pattern of engagement. While Allison engages with the workshop primarily as an artist, Dakota engages primarily as an engineer.

Given that Robot Diaries was specifically designed to blend artistic and engineering approaches to technology, I believe that each of these patterns is a valid response to the curriculum. Furthermore, the existence of these different patterns of participation supports the assertion that Robot Diaries allows girls to engage with technology in more than one prescribed way, making this a useful platform for promoting technological fluency among diverse audiences.

3.2 DATA SOURCES

This analysis focuses primarily on participants' actions during the three robot design sessions (sessions 2, 3, and 4 of the overall workshop; see description below) and any home activities occurring during this time. Within each design session, analysis focuses on participants' actions and reflections as they relate to the three habits of mind (Yin, 2009). In other words, the analysis of patterns of thinking occurs within the habits of mind framework.

The descriptive data provided in this chapter was drawn from multiple sources of evidence, including interviews, documentation, direct observation, and physical artifacts (Yin, 2009). Interview data comes from the researcher's interviews with participants and their parents, and from participants' interviews with each other (participants conducted short interviews with

[10] All names are pseudonyms.

each other twice during the workshop). Documentation includes workshop video, photographs, and e-mail messages sent to the researcher from parents. Direct observations during workshop sessions were supplemented with field notes. Physical artifacts include participants' design journals, participants' video journals, homework assignments (e.g., robot collages), programs written during the workshop or at home, entries on the community message site, and content (text/photos) posted to participants' community websites.

3.2.1 Robot Design Sessions

The Robot Diaries workshop took place over a series of 6 sessions, for a total of approximately 16 contact hours. During the first session, which was four hours in length, participants were introduced to both the hardware (e.g., LED's, motors, servos, the Hummingbird) and custom software they would be using, and given a chance to explore each.

Participants began to design their own robots in the second workshop session. During this session, instructors described and discussed the design process, and then introduced the robot building task by explaining that each participant would be building and programming her own expressive robot, and that they would have time during the next few workshop sessions to redesign/improve/change their robots. Participants were provided with the following materials during this *first robot design session*: a handout about the design process, a handout describing the robot building task along with pictures of previously built robots using similar materials (see Appendix E), two servos (actuators), two tri-color LED's, a hummingbird (processor board), foam board, craft materials (including hot glue, tape, and wire ties for attaching components), and blank paper for sketching. Participants were explicitly instructed to produce a sketch at the start of each robot design session. Participants were told that they would be getting additional materials (e.g., more motors, servos, sensors) in the weeks to come, but were strongly encouraged to produce a working robot with the materials provided during this first session. In response to numerous questions from participants about how to structure their efforts (e.g., should they sketch out what the robot will look like at the end, or what they would/could build today? what should they do if they had a design that required more than the number of parts they would be receiving today?), the instructors reiterated the goal of creating a robot that could be expressive, and reminded the girls that they should have a working robot by the end of that day's session. One of the instructors also emphasized the importance of thinking through structural issues, like how to make the robots stand up on their own. In response to the second query, the instructors suggested that the girls pick the parts of the robot that would be most important for allowing it to express emotion, and focus on completing those parts. The first design session ended with the girls playing robot charades – instructors assigned each girl an emotion, and the girls had to program their robots so that others in the class could guess the emotion.

During the *second robot design session*, participants again discussed the design process (this discussion focused on iteration in design) and were then given an opportunity to iterate on their robot design. They were provided with the following additional parts: 2 servos, 4 (single color) LEDs, 2 vibration motors, 1 full-rotation motor, 1 speaker, and an additional handout (see Appendix F) with re-design suggestions. Once participants had added the new components on to their robots, each girl was asked to program two emotions into her robot and the group played a game called Robot Mad Libs, where the instructor read a story and the girls used their robots to contribute emotions to the story at pre-determined spots.

During the *third robot design session*, participants continued to work with the additional parts they were given. The session included a Show and Tell activity, where the girls had the opportunity to show their robots to the group and give/receive feedback on their designs.

In total, participants spent 3 workshop sessions (~ 10 contact hours) designing their robots and iterating on their designs. Participants were provided with a motion sensor and a light sensor after they completed the 3 robot design sessions.

3.3 ANALYSIS APPROACH

The purpose of this analysis is to explore the similarities between each girl's actions in the workshop, and the 'artist' and 'engineer' patterns of engagement described above. This approach is similar to Yin's (2009) description of pattern matching.

The definitions of 'artist' and 'engineer' suggest a starting point for analysis. After reviewing and summarizing the available data, I used these definitions to develop a set of claims about each participant. These claims were revised and synthesized in light of the three habits of mind. Then, I queried the data set to collect evidence in support of/against each claim. Multiple sources of evidence were triangulated to support each conclusion (Yin, 2009).

Table 1 displays the claims developed for each of the participants. In the remainder of the chapter, I first provide a narrative description of each participant's engagement during the three robot design sessions. Then, I re-state the claims made about her participation and summarize the evidence in favor of (or opposing) each claim. Finally, I conclude with a comparison of the different patterns of participation represented within the data.

Table 1. Claims about the participants

	Allison	**Dakota**
Engage in Design Process *What did she do?*	1. Allison's design plans are not strict guides for her robot building activities 2. Allison generates a lot of ideas, but often relies on others to evaluate the technical feasibility of those ideas 3. Allison's design choices are primarily motivated by expressive goals	1. Dakota is generally planful in her designs and faithful to those plans 2. Dakota routinely engages in the generation and evaluation of design ideas, and is effective at troubleshooting her own ideas 3. Dakota's design choices are motivated by technical and expressive goals
Beliefs About Technology *What beliefs do her actions represent?*	4. Allison has developed creative solutions to meet her expressive goals 5. Allison sees her robot as a representation	4. Dakota has developed creative solutions to meet both technical and expressive goals 5. Dakota uses the robot as a platform for furthering her own interests
Confidence *How did she feel about it?*	6. Allison is hot and cold in her confidence with the technical elements of robot building	6. Dakota is confident about her abilities as a builder/engineer

3.4 DAKOTA

3.4.1 Workshop Engagement

Daktoa was 14 years, 1 month old at the start of the workshop. Dakota has a wide range of interests, including music (she plays the piano and cello), recycled art, and jewelry making, as well as technology and robotics. She has previously taken a robotics class through the home school enrichment program, which focused on building mechanical contraptions. Dakota also enjoys math and science, and showed me some of her current science experiments during our initial interview. Dakota's father is an engineer [pre interview]. Her younger sister Chloe also participated in the Arts and Bots workshop. Dakota estimated that she spent between 2 and 3 hours per week working on her robot outside of the workshop [final interview].

Given her prior experience, it is perhaps not surprising that Dakota came into the workshop with an idea about the type of robot she wanted to build.

> Before I started coming to the classes I wanted it to be a lizard, and I wanted it to climb up walls and stuff. But then I came here and I saw that we had Styrofoam. I thought we were going to be working with metal. But I saw that we had Styrofoam so I thought of a lizard-dog. So it was going to open its mouth like that, and then have a tail that wagged [Dakota in-class interview, 10/30/08; Dakota also discusses this in her midpoint interview]

Dakota explained the source of her original idea during a later interview:

> Dakota [D]: Well, I saw something on TV that could climb up walls and I'm like oh, a lizard that was camouflaged because it had LEDs all over it.
> Researcher [R]: Yea.
> D: You could have different colors and adapt to its surroundings and stuff. I thought that would be really cool.
> R: It was a robotic lizard?
> D: That was my idea, but their idea was just a robot that was plastic that could just climb up walls.
> R: Yea.
> D: It looked sort of like a lizard, more like a frog.
> R: Oh, so the LEDs all over the place that can camouflage, that's your – that was your idea?
> D: Yea.
> R: That's a nice idea.
> D: Yea, and it was a little bit sad but you know it was a little bit like expensive. It probably would have taken a lot of money to build that.
> R: Well, you might have needed a fair amount of LEDs.
> D: Yea, and then you would have needed a lot of hummingbirds too. So it was a little bit big of an idea.
> [final interview]

Dakota's original idea (influenced by something she saw on TV) was a robot that could climb up walls and camouflage itself. As we will see from her first design sketch, Dakota realized rather quickly that she would have to modify her original design. By the time of her final interview, she is able to give a host of reasons why her original design would not have worked – the idea would have been too expensive, and there was not enough room on the processor board[11] to accommodate the necessary components.

3.4.1.1 Robot Design Session #1

Sketch. Below is Dakota's sketch from the first robot design session.

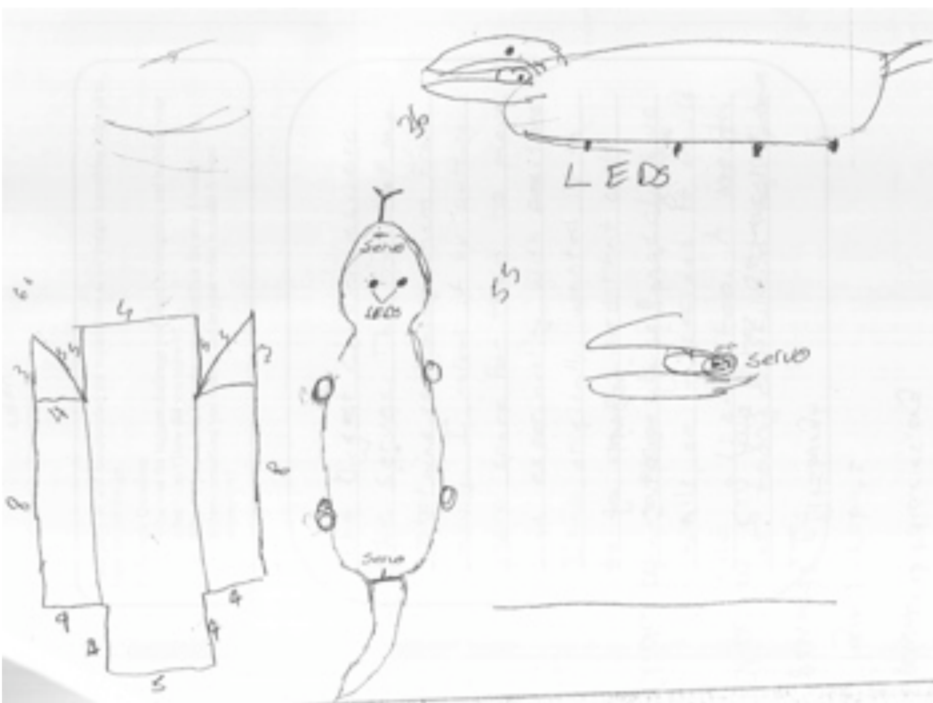

Figure 1. Dakota's sketch from design session #1

[11] This comment was likely a reference to the limited number LED's that could be plugged into the hummingbird.

In this sketch, Dakota draws top and side views of her robot and provides a close-up of the robot’s mouth (and servo placement in the mouth). Dakota’s preference for the robot’s shape is evident – the robot has a rounded body in several of the sketches. She also labels technical parts on her sketch, including servos for the tail and head, LED’s for the eyes and feet, wheels on the side of the robot[12] [final interview], and provides a schematic for how she will cut out the body.

During this session, Dakota successfully cuts out a body for her robot, designs a moving head, adds two LED eyes to the top of the head, and adds a moving tail. Both the head and the tail move using a single servo each. (See Figure 2). The lights on the bottom of the robot (as previewed on her sketch) are added during the third robot design session.

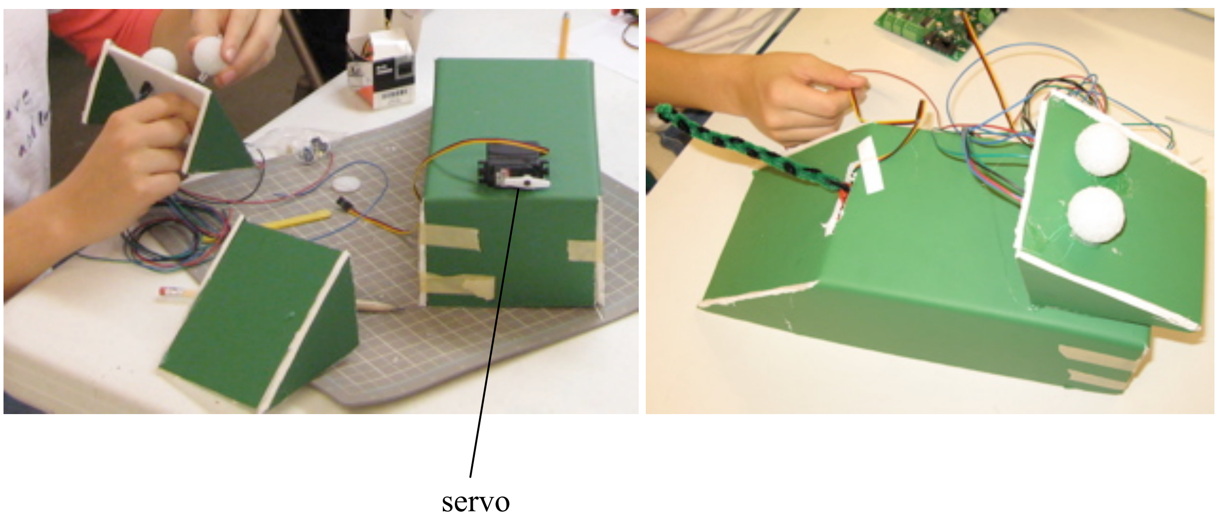

Figure 2. Images of Dakota’s robot from design session #1

In her robot collage (created as part of a homework assignment near the end of the workshop), Dakota explains that the robot (later named Riley) uses its parts to express emotions. For example, the robot’s eyes “express emotions by changing different colors depending on Riley’s mood”, the tail “helps to express emotion by Riley wagging it fast when he is happy, and

[12] In her final interview, Dakota explains that the round appendages on the sides of the top-view robot are wheels.

vice versa when he is sad", and the head "helps him to relate to humans and makes him seem like he understands you. In addition, it's good for dancing!" [collage].

Build. Dakota begins the session by cutting out the robot's body. The shape of the body is one of the more distinctive aesthetic features of Dakota's robot. Dakota's is one of four 3-dimensional robots that were created in this workshop, but it is the only one where the entire body was cut out of a single piece of foam board and folded (as opposed to cutting out single pieces and gluing them together to create a 3-d robot body) [field notes 10/9; workshop video RD_c2_10-9-08]. In the lower-left corner of Dakota's sketch (Figure 1), we can see that she carefully planned out the dimensions for her robot's body. In later interviews, Dakota explained that she chose to cut the body of her robot from a single piece partially for aesthetic reasons – this cut yielded rounder edges than the alternative approach of gluing individual pieces together, resulting in a more "natural" look for her robot. This idea came from a crafts project she had done in the past [midpoint interview; final interview]

A review of the workshop video indicates that prior to building, Dakota had a brief conversation with Carol (a workshop instructor) about the shape of her robot. Dakota shares some of her initial ideas for achieving her desired aesthetic (e.g., by adding a wedge), and Carol also makes some suggestions (e.g., making a mound of foam pieces and covering them in fabric). They also discuss some of the sample robots seen in a handout, and how they were built [workshop video RD_c1_10-9-08.mov]. It is not clear whether Dakota had a 3-dimensional robot in mind before talking to Carol, or whether Carol introduced that idea with her suggestion of making a mound and covering it with fabric. Although, field notes suggest that Dakota introduced the 3-D robot idea [field notes, 10/9/08]. Interestingly, Carol and Dakota do not seem to discuss Dakota's ultimate solution for making her robot round – folding up the sides. Indeed, Dakota's midpoint interview transcript reinforces the notion that this was her idea – she had tried it before during a craft project.

It is also interesting to note that while the overall goal of the single-cut body was aesthetic, Dakota's route to this goal was precise and mathematical. In a later interview, Dakota explains that the numbers on the sketch represented measurements, and that she was conscious of making her robot's dimensions precise.

> D: I tried to just think everything out before I did it… Just that, I was trying to figure out if this side is five [indicates length of slanted portion of robot], and then this side have to be five but this is three [points to bottom of triangle formed by slanted back] – yea this is three and then this is four [indicates hypotenuse]. So this side is smaller but yet it goes the same distance 'cause it's not going down.
> R: Oh, you mean –
> D: Like it wasn't a box. It was a triangle which is a little difficult…But it worked, pretty much. Except for this… [points to part of robot protruding beyond slanted part of robot]
> R: I think it worked really well. Your centimeter not withstanding. Okay. So it seems like that – like this took a little time to kind of work out.
> D: Yea. It probably took me about ten minutes.
> R: Are you a math person? Like do you like math?
> D: I like math. Yea, it's fun.
> [final interview]

After cutting out the robot's body, Dakota begins to work on its head. As is evident from the sketch, Dakota's initial idea about the robot's head was that it would be two parts held together with a servo [final interview]. However, the final version of Dakota's robot has a different head than the one she originally sketched out.

In the workshop video we can see that, as per her original idea, Dakota made 2 separate head pieces (see left-hand photo in Figure 2) and played around with them for a bit – moving them against each other as if they were hinged to form a single mouth that could open and close; she also tries placing them on both the slanted end and flat end of her robot. In the end, however, she winds up using only one of them on her robot [RD_c2_10-9-08.mov, 26:57 – "maybe I'll just use one"]. She glues a single servo to the robot's body (see picture above), and then places one piece of the foam board head over the servo. The head piece is hot glued at the corners where it meets the robot's body, to create a type of hinged movement when the servo moves [final interview, workshop video RD_c2_10-9-08]. As Dakota noticed later, the moving part of the servo (called the 'horn') actually created a ditch in the foam, which facilitates this movement [final interview].

Dakota does not articulate her reasons for changing her head design during the actual workshop session, but her commentary during the final interview (below) suggests that she realized the placement of the servos in her original design would be a problem, as was her misunderstanding of how the servos moved:

> D: I was [originally] thinking with a spoon, like two spoon shapes open it's mouth like that. [makes a hand gesture with palms together and both hands moving up and down]
> R: Oh, neat.
> D: But I decided – I actually made two parts of the head, but then I realized that it wouldn't really work because you can't put the servo anywhere, 'cause if both of them are (?) going to open up then the servos in mid air.
> R: Right.
> D: So, I just made one head that went like that. [gestures with palms together but only top hand moving]
> …
> R: [points to mouth portion of sketch] And so then you've got the servo and these are the two parts of the mouth you were talking about
> D: And I thought – and then I thought servos went all the way around basically so it could go open.
> R: Right.
> D: And it really – it would have had to be in the middle and then it have to open one part and then open the other part, which sort of –
> R: wasn't quite what you had in mind?
> [final interview]

While the single head was not Dakota's initial idea, she described this solution to her robot's head movement with a certain degree of pride. When asked about the most unique aspect of her robot, she responds, "Um, I think the way it moves its head up and down. Because of the servo underneath 'cause it moves in a circular pattern. So when [the servo horn is] straight across, it's down and when it's up and down then it moves its head up" [final interview]. Even when she re-builds the head in a future session (to accommodate the addition of ears), she makes sure to maintain the hinged head movement used in this early version of her robot.

Dakota's other major addition during this session was the tail. During the workshop session, Dakota and Carol had a conversation about the movement of the tail, which was unfortunately hard to hear. However, during the conversation Dakota is heard asking Carol questions about how the servo and horn can move, because she wants a 'tail to wag' [workshop video RD_c2_10-9-08.mov]. As she describes in her final interview, her initial idea for the robot's tail was to have it wave back and forth, although the robots' tail actually moves in more of an arc. Dakota explains, " I really didn't understand the parts that we were going to get." This could be a reference to the type of movement created by a servo, which arcs rather than moving directly back and forth.

Dakota winds up hot gluing a servo underneath the robot's body to control the tail. She then takes 3 pipe cleaners and braids them together to make a visible portion of the tail, and attaches it to the servo. This solutions works well for her, although it did require some modification – the original slit for the robot's tail was not large enough to accommodate the motion of the servo horn, so she needed to make it larger [final interview].

Program. At the end of this session, the girls were each asked to program an emotional expression for their robot as part of a Charades game. Dakota encountered some problems with her robot's tail while programming. The tail servo popped off and needed to be re-attached. Dakota also encountered some problems with the way the robot's head was moving [workshop video RD_B3_10_9_08]. However, by the end of the charades game Dakota has successfully programmed her robot to express the emotion 'suspicious' by wagging its tail, moving its head, and lighting up its eyes.

While programming, Dakota asked Carol if she'd be able to continue using the robot in this way at home. Carol tells her she can, but that Dakota's mother has not yet installed the programming software on their home computer. Dakota asks if she could do the software installation, and Carol gives her the relevant log-in information for downloading the software [workshop video, RD_c3_10-9-08].

Dakota's program is well received when she shares it, and the group generates a number of suggestions about what she could add to her robot, including a tongue and ears[13]. Dakota mentions that she might want to add a mouth and eyebrows [workshop video RD_c3_10-9-08.mov; reflection 10/9]. Dakota does add ears to her robot during the next session, but never adds the tongue or mouth. During her final interview, she explains that she never added the tongue because, "I really couldn't do anything with a tongue because it's sort of, you know, all in there [points towards back of head] and there's nothing, no more room to put a vibration motor for the tongue or anything." Dakota also eventually decides not to add a mouth to her robot because it would have restricted the range of possible emotions her robot could express:

> D: And I didn't draw like a mouth or anything because really the mouth was down here and I didn't want it to be smiley or anything like that, so.
> R: How come?
> D: Because if it's smiling it can't be angry. It doesn't look angry. If it has no mouth then it can look angry.
> [final interview]

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[13] During a later interview with another participant, Dakota answers the question 'did your ideas change in class activities?' by saying, "Yes, I actually added the ears because of that to make it more, more emotional and I added the speaker" [Dakota in-class interview, week of 11/6/08]. However, it is not clear if she's referring to this exchange or just saying more generally that the idea for ears emerged during class.

While displaying her program, the girls ask Dakota what type of animal her robot is supposed to be. Earlier in the session she described the robot as a gecko, and then as a lizard, 'part dog', and a lizard dog. During Charades, Dakota replies, "it's supposed to be a lizard dog, because of it's tail. Lizards don't really have tails that do that, but oh well" [RD_c3_10-9-08.mov]. In later workshops and interviews, Dakota describes her robot as a dog or alligator dog, but maintains a sense of humor about her own ambivalence towards the robot's form.

> R: So if somebody looked at the robot you built, what do you think they could tell about you?
> D: About me?
> R: Uh huh. About the builder, about the creator.
> D: Um, that I really didn't know what I was thinking of as the animal at first because usually you don't have green dogs.
> R: {laugh}
> D: And I think also that I can figure out things logically pretty well like the shape of the base of the robot that I cut out and then like the ears moving and stuff like that.
> R: Cool. So they could tell that you know how to do some of those things?
> D: Yea.
> R: Okay. Is there anything else you think your robot says about you?
> D: Um, that I have a sense of humor. {laugh}
> [midpoint interview]

Dakota is similarly candid about naming her robot. The robot's name, Riley, is used in the collage Dakota makes towards the end of the workshop. However when asked about the name of her robot, Dakota admits that the naming process was haphazard. She originally wanted to call her robot 'RoboDog', but her mother prevailed on her to give it a more creative name [final interview].

At Home. Over the course of the week, Dakota posted 4 programs for her robot on the messenger (the programs were called: suspicious, sad, play, agree). She also shot 2 videos explaining where her robot would live in her house (this was part of a homework assignment) – the robot would be 'staying' in her room, but it would be used on the computer in the basement [home video VID00025, VID00027; final interview].

3.4.1.2 Robot Design Session #2

Sketch. Figure 3 shows Dakota's second robot sketch, made at the start of the second robot design session.

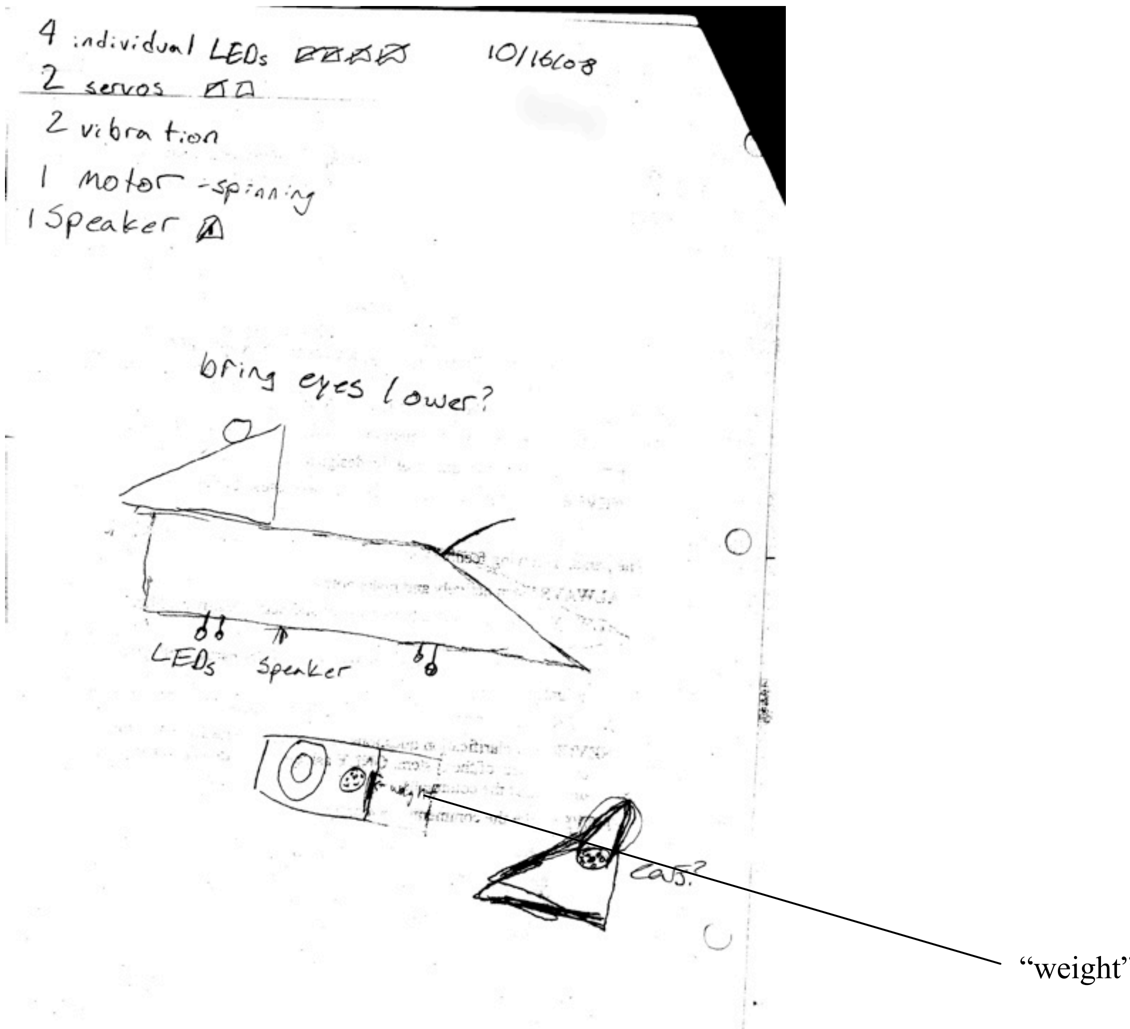

Figure 3. Dakota's sketch from design session #**2**

The main features of this sketch are the robot's head (eyes and ears), LED feet, and speaker. On the top of the sketch, Dakota has noted all the additional parts she will have available to her as she iterates on her robot design.

Dakota spent the majority of this session working on her robot's head. As can be seen in the lower right corner of the sketch, she is considering the addition of ears. By the end of the session, she has added ears to her robot and re-built its head (the head re-build was a necessary consequence of adding the ears). The LED legs were also present in her first robot design sketch, although she does not end up adding them until the third robot design session. Likewise with the speaker, which is added during the third robot design session. It is interesting to note, however, that Dakota has already started thinking about where the speaker might go. At the start of the session, Dakota asks about the weight of the speaker and the instructor passes one around so the girls can feel how heavy it is [workshop video RD_a1_10-16-08]. Dakota's note about a "weight" might have been a reference to the speaker, or to the need to add a counterweight for the speaker. But this is speculation on the researcher's part – Dakota never explains this note on her sketch.

Figure 4 shows front, back, and 'inside' images of Dakota's robot during this design session.

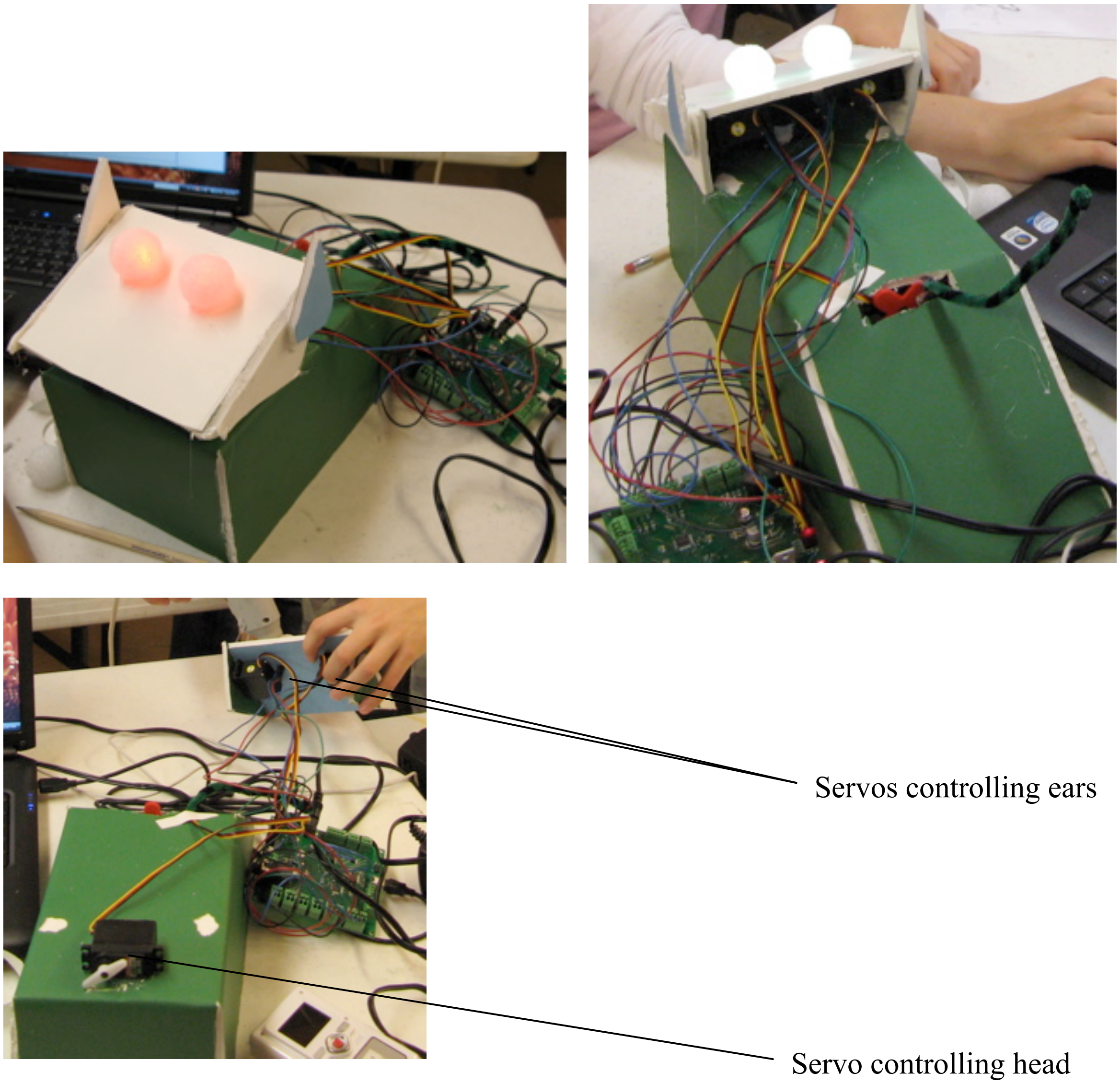

Figure 4. Images of Dakota's robot from design session #2

Build. In her first design journal entry, Dakota indicates that she is interested in adding eyebrows to her robot [reflection 10/9/08]. Dakota repeats this idea during the group discussion that takes place at the start of this session, saying she is interested in adding 'eyebrows and maybe a mouth' [RD_a1_10-16-08.mov]. However, as her design journal from the end of the second session indicates, she changed her mind about adding eyebrows and instead added ears:

> "I made the ears because I thought, like eyebrows, dogs use their ears to communicate. My robot couldn't really act sad during the week and the ear help it look more sad. I think my robot can express as a result from both eyes being blue, and the ears being able to perk up and droop." [reflection 10/16/08]

Dakota expands on this idea during her final interview, suggesting that ears may be more appropriate for her dog-themed robot than eyebrows:

> R: So why did you decide to put on ears?
> D: Um, because I was thinking more about dogs now instead of lizards, and then dogs have ears and that's really how they communicate because they don't really have eyebrows or anything. They do, their ears wag and you know stuff like that. So I had a tail and ears and a head and it was a dog.
> [final interview]

In addition to the thematic reasons for adding ears to her robot (i.e., dogs have expressive ears, not eyebrows), a comment during her midpoint interview suggests that Dakota might have had some functional reasons for adding ears instead of eyebrows:

> D: Oh, um, I wanted to put on eyebrows but I couldn't think of any way that they could go up and down. So I decided because it's a dog, dogs really don't have eyebrows so much. They have ears, and their ears work as their eyebrows do for humans.
> R: Hmm. So you kind of added the ears in lieu of eyebrows.
> D: Yes.
> [midpoint interview]

Dakota's comment about the difficulty of making the eyebrows go up and down is likely a reference to the type of motion enabled by the servos (servos move in an arc).

Regardless of the reason, adding ears required Dakota to re-build the robot's head – she needed to widen it to accommodate the two additional servos for the ears [midpoint interview, final interview]. An examination of the workshop video reveals the process that led to the head re-build.

> First, Dakota cuts out two triangular ears and experiments with them by holding them up to the side of the robot's head and spinning them around. Dakota then carefully removes the head from her robot, and asks Meg for two servos (presumably, to control the robot's triangle-shaped ears). Dakota then places a servo inside the robot's head, and returns the robot's head to its body. She measures the width of the head with a ruler, and then uses

an exacto-knife to shave one side off of the robot's head (she also removes the robots' eyes). As Dakota explains to Meg, she will need to make a larger head to accommodate two servos for her robot's ears.

After removing the eyes from the robot's head, Dakota cuts out a new front piece for her head (in the photos above, the white front of the head is the piece she replaced). It is hard to know from the video how precisely she measured/planned the size of the new head piece. However, on camera she can be seen holding it up for comparison with the piece it is replacing.

Once Dakota has completed the new head, she acquires two small cups from the craft table which she trims and then briefly plays around with inside the robot's head. However, she quickly abandons them on the table. Following this, she attaches a servo to the side of the head, and then plugs the servo into the hummingbird and opens the software, likely to examine the motion allowed/created by the servo she has just added. After examining the range of motion, she removes the servo she had just added, pokes holes in the side of the robot's head, and eventually adds two servos – one on either side of the robot's head.

The third picture in Figure 4 shows a view of the inside of the robot's head, with a servo on either side. The servo that tilts the head up and down will sit in between these two ear servos, once the head is re-attached to the body. Eventually, Dakota hot glues the foam ears onto the servo horns (on the head's exterior), although here she has to remove and replace one ear after realizing that it spun backwards instead of forwards. However, she did spend a fair amount of time moving the servo horns back and forth before attaching the ears – it is possible that she was trying to 'center' the servo (i.e., find the center point of the servo's motion) before gluing on her ears. By the end of the session, she has glued the head back on to the robot (she does this by gluing the corners of the head to the robot's body, so that the head can still tilt up and down) and attached both ears. [workshop video RD_a1_10-16-08, RD_c2_10-16-08]

Dakota later points out that she purposefully placed the ear servos inside the head, instead of on the body where they would have broken off when she moved the head [final interview].

Program. Dakota programmed two emotions for her robot during the Mad Libs game at the end of this session – one program called 'listening' and another called 'confused'. Unfortunately, neither of these programs is visible on the workshop video (someone is blocking the camera each time).

When asked about how she programs expressions on her robot, Dakota suggests that it requires some experimenting to 'get the right emotion that you want,' and that the process includes thinking about how people and dogs might express emotion:

> R: How has the programming struck you?
> D: Um, I think it's fun but you have to experiment to get the right emotion that you want.
> R: Okay. Can you say a little more about that?
> D: Um, I think that might be a little bit harder to me because you can't really logically think it out so much. You just have to experiment with the lights and the ears and the tail, and you have to think of a real dog to really get that emotion out.
> R: Oh, yea. So you think about a real dog when you're programming your robot?
> D: Yes.
> [midpoint interview]
>
> R: Um, so can you tell me a little bit about how you program expressions onto your robot? Like what do you think about and can you break it down?
> D: Uh, I like the fun ones like the dancing things. So I was thinking about the timing and I wanted to make it sort of look like it was dancing. And then for other things like making it angry I think about what I look like when I'm angry or what someone else looks like when they're angry because I don't really look at myself when I'm angry. What makes me angry and why, what expression do I use, and then dogs too. When they're angry or they're scared or something.
> [final interview]

Dakota also explains that certain parts on her robot are good for certain emotions. For example, "the tail is mostly happy I would say. Except if I just had it stationary it twitches [touches tail] and that's good for angry… The ears can be sad and happy [touches ears], but not really angry so they're just going to be up for angry. And the head is used for everything, and the eyes too" [final interview].

At Home. Dakota posted three additional programs on the messenger this week (titled: awakening, hungryears, loving), and shot three videos of her robot performing various programs. Dakota also covers the robot's ears in green felt [final interview].

3.4.1.3 Robot Design Session #3

Sketch. Figure 5 shows Dakota's third robot sketch, made at the start of the third robot design session.

Figure 5. Dakota's sketch from design session #3

This sketch provides an accurate representation of Dakota's robot thus far (eyes, ears, head, a tail) and includes the elements she plans to add during this session – the LED's underneath the robot, a speaker, and a 'booster box' which would lift the robot of the ground and provide a place for the heavy speaker. The two sketches at the bottom of the page are preliminary designs for the booster box [final interview].

The pictures below illustrate the changes to Dakota's robot during this third design session. The first picture was taken during the workshop session, and shows the LED's underneath the robot. Notice how the robot is lifted off the ground slightly – this is because of the booster box, which had already been added to the robot when this picture was taken. The second picture illustrates the booster box, and was taken during Dakota's final interview.

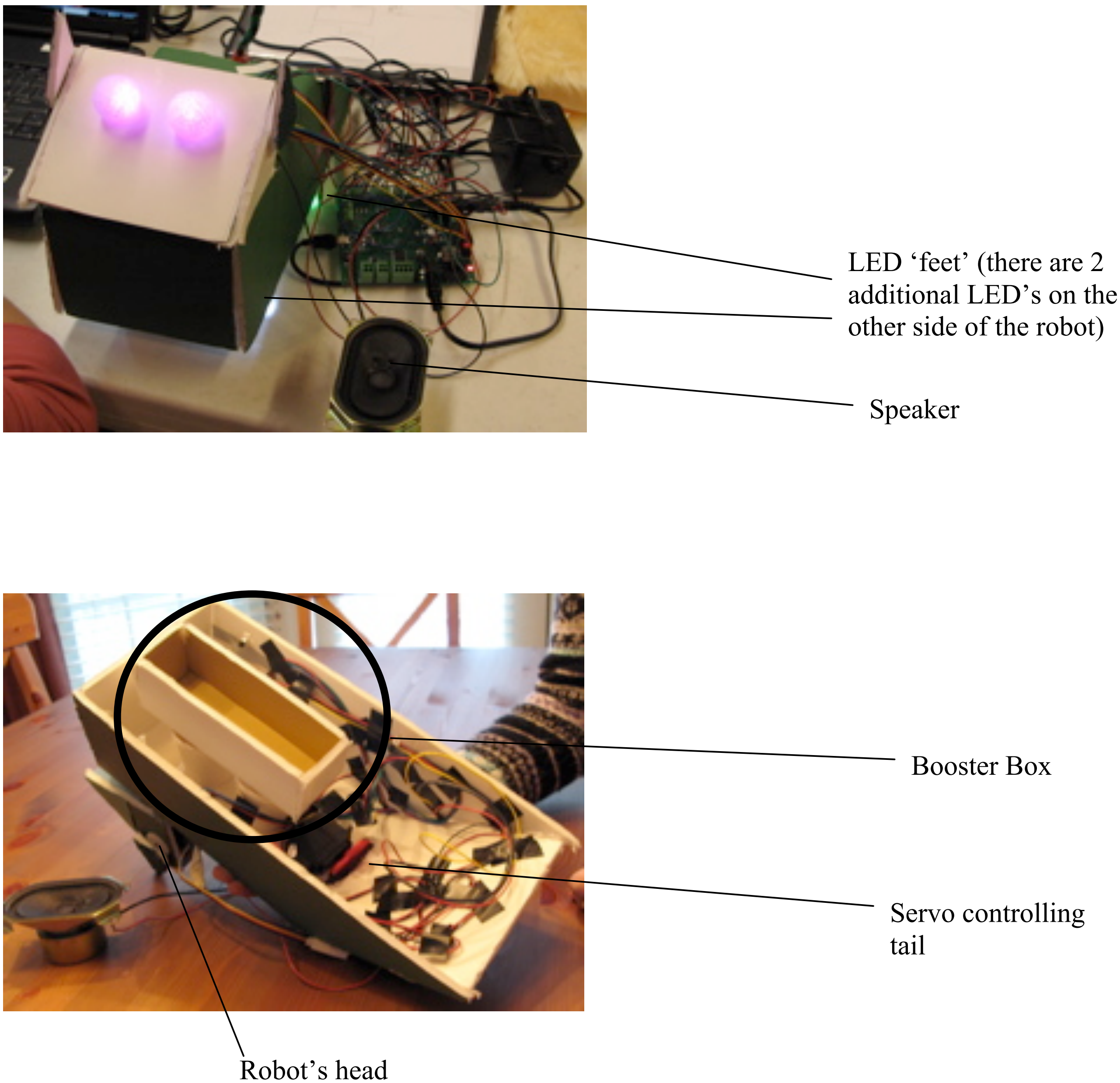

Figure 6. Images of Dakota's robot from design session #3

Build. One of Dakota's goals for this workshop session was to add a speaker to her robot. As we can see in her sketch (Figure 5), she experiments with different locations for the speaker [final interview]. The lower side view of the robot shows the speaker attached the front of the robot (on the inside), right underneath the head. While Dakota was making this sketch, she asked Meg (workshop instructor) whether the speaker would stay if she glued it to the inside of her robot. Meg responds that the speaker doesn't necessarily need to be glued to the robot – it could just sit nearby [workshop video RD_a1_10-23-08]. Dakota designs the booster box to support the speaker [final interview].

A review of the workshop video indicates that Dakota cuts out the booster box in the same way as the robot's body – as one piece with flaps that get folded up [field notes 10/23]. Her original design (as seen in the sketch) is for the booster box to have a single column. But Dakota decides that the box would be more stable if it had two columns [final interview]. In the end, the booster box is a rectangular box with two paper cups glued to the top of it. The booster box sits in the robots with the cups facing up. After attaching the box Dakota tries to place the speaker underneath the robot, but it does not fit [workshop video RD_a1_10-23-08]. It eventually ends up just sitting on the table.

While the original intention of the booster box might not have been realized, Dakota articulates another purpose for the booster box during the workshop session – to get the robot off the ground so the feet would be visible [field notes 10/23/08; workshop video RD_a2_10-23-08].

Dakota adds four LED's to the bottom of her robot, to serve as 'virtual feet.' While the idea for the LED's underneath the robot were present in Dakota's first robot sketch, it is not until this week that she finally adds them to her robot. Dakota explains during an exchange with the researcher on the community messaging site that her original intention was to use the lights as an additional expressive element. However, she later changed her mind about the use of the lights:

> R: [message titled 'lights on your robot'; 10/26/08] Hi Dakota, I really liked how you put the lights on the bottom of your robot, to make it look like it is walking. I was just curious – how did you come up with that idea?
>
> D: [message titled 'Thanks!'; 10/28/08] I decided to put lights on the bottom of my dog because I had seen cars have lights on the bottom rim, and I thought I could convey emotion with the light. But then I decided that it would be a little hard with only one or two colors of lights. Then the lights sorta looked like feet, and I so I decided that's what it would be!

This use of the lights (as feet for her robot) is also reflected in Dakota's design journal for this session:

> I put 4 LED's underneath the robot, to symbolize feet. That way my robodog can move without actually changing it's position… My ideas about what I want my robot to do changed from my original ones, because I wanted it to scale up walls, but now it is moving virtually! [reflection 10/23; Dakota also describes how her 'virtual feet' tie back to her original idea of scaling walls in an in-class interview on 10/30].

In later interviews, Dakota also indicated that she made another functional decision around this time – the choice not to add wheels to her robot. It was during this session that Gabrielle – who sat next to Dakota in the workshop – discovered wheels mixed in with the workshop supplies, and added them to her own robot. But as Dakota explained in her final interview, she took wheels home from the workshop with her but did not use them because she could only have two (due to a limit in the number of available motor ports) and she did not think two wheels could support her big and heavy robot [final interview].

Finally, Dakota thinks about adding fur to her robot during this session. In the workshop video, she can be seen holding dark fur up to her robot, and even asks an instructor if she can take the fur home with her (the instructor says yes) [workshop video RD_a2_10-23-08]. But in the end, Dakota decided not to add the fur to her robot. As she comments during her final interview, “I was going to put on fur. I brought home fur, but I decided I liked it being green. So I didn’t want to loose that.”

Program. Dakota does not demonstrate any programming for the workshop group, but she does experiment with programming during the session, for example by writing a program that makes the robot look like it’s begging for food [workshop video RD_a2_10-23-08].

At Home. At home Dakota participated in a group story by posting a program called ‘please’ for her robot. She also shot movies of the robot dancing to music [home video VID0035] and a “spoof on presidential campaign videos” [home video VID0037] which featured her robot expressing its support for Senator Obama’s presidential bid.

3.4.1.4 Additional Changes

During the week following this session, Dakota attached the hummingbird to the back of her robot using Velcro (Figure 7).

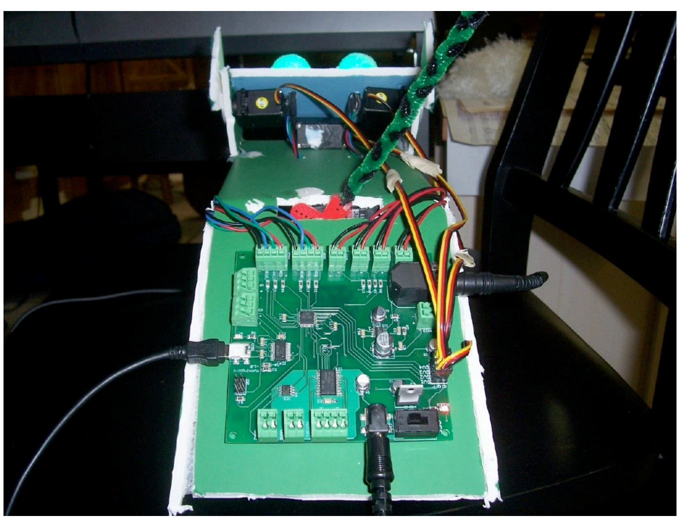

Figure 7. Dakota’s robot with attached hummingbird

In her final interview, Dakota describes how the wires were in a 'nest' that she just couldn't 'work with,' prompting her to think about a new solution for her wiring. Dakota reports taking 'everything off,' although she was careful to number all of her wires so that she could make sure to re-attach the components in the same places as before. Dakota then explains how she and her father (an engineer) jointly devise a solution to the 'nest' problem – attaching the hummingbird to the back of the robot. It is Dakota's father who offers up the Velcro – a previously unknown resource – that Dakota uses to attach the Hummingbird to her robot [final interview].

Dakota's desire to move the hummingbird off of the table and attach it to the robot seems to be a functional, but also partially aesthetic choice. While a 'nest' of wires can inevitably make electronics more difficult to deal with, it also makes them ugly. While Dakota does not specify that she had aesthetic motivations here, such an assumption fits with a subset of her actions and comments. For example, one of her ideas was to put the hummingbird underneath the robot, which would have completely hidden all of the wires. Also, when describing the wiring underneath the robot, Dakota commented that the wires are "wound around everything. So they come out right here, with the least wire amount possible" [final interview].

The other change to Dakota's robot is the addition of the light sensor (see Figure 8). The instructors introduced light and motion sensors during the following workshop session. Dakota eventually incorporates the light sensor into her robot, and makes a program called 'sir-dance-abot' which uses the light sensor to trigger the robot's dancing in sync with the music [final interview].

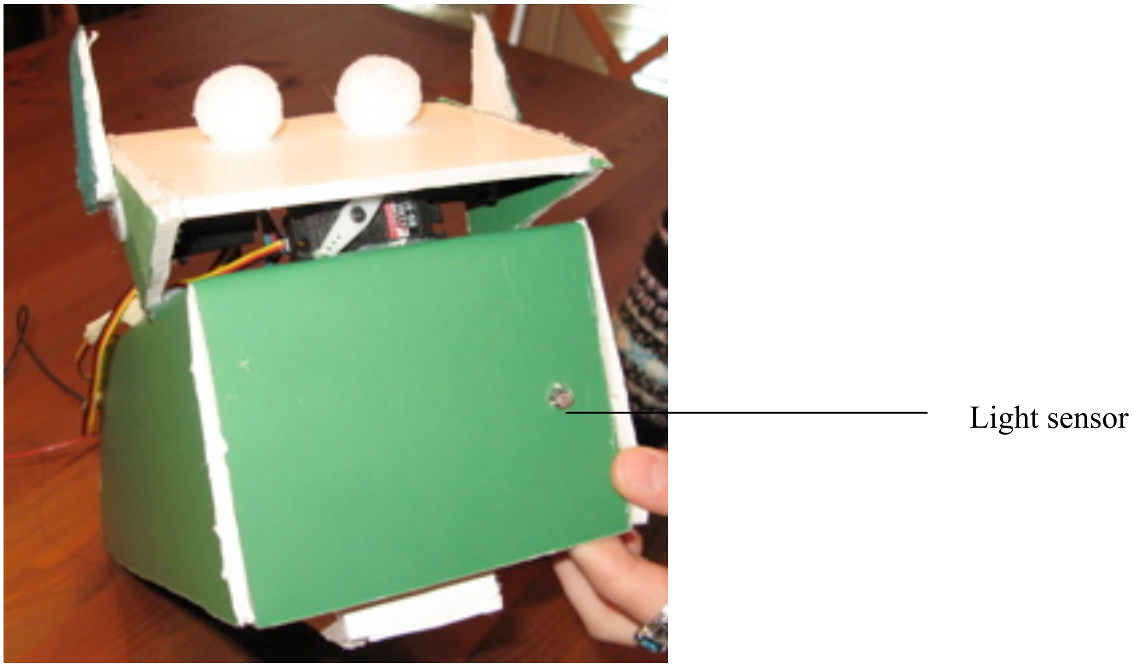

Figure 8. Dakota's robot with sensor

3.4.2 Summary of Evidence

Dakota engages with the Robot Diaries workshop primarily as an engineer. She is an effective designer in the engineering sense – she is planful in her design approach, respectful of technological constraints, and accurately evaluates the technical feasibility of her own ideas. Dakota develops creative solutions as a means of meeting some of her engineering goals, and often offers technical motivations for her designs. However, Dakota also engages with the artistic side of the workshop. This engagement is most evident when Dakota offers expressive motivations for her designs, develops creative solutions as a means of meeting expressive goals, and uses her robot as a way to express her interests.

Claim 1: Dakota is generally planful in her designs and faithful to those plans

Evidence gathered from design journals, workshop video, photographs, and interviews suggests that Dakota developed detailed design plans for her robot at the start of each session, and was generally faithful to those plans. While the specific implementation of her design ideas often changed, she never introduced any elements into the robot that were not previewed in her sketches.

Session 1. Dakota's first sketch showed a robot with four feet, eyes, a tail, a tongue, and a rounded body. The sketch also specified that this robot would contain two servos (one in the mouth, one in the tail), LED's on the feet and eyes, wheels, and a body of specific dimensions [sketch 10/9; final interview]. A number of these elements were implemented during the first design session, including LED eyes, a servo-controlled tail and mouth, and a rounded body (roughly adhering to the dimensions specified in the sketch) [workshop video and photographs, 10/9]. The LED feet were implemented during a later design session. The only elements on this sketch that were not eventually implemented in the robot were the tongue and the wheels (although Dakota later programs the LED's as 'virtual feet' in lieu of the wheels).

All of the elements added to the robot during this session were previewed on this sketch, although once she started building Dakota did evaluate and change some of the specific designs (for example, the mouth on the final robot looks somewhat different than the mouth specified in the sketch).

Session 2. Dakota's second robot sketch showed an accurate representation of her robot as it appeared at the start of this session, with three additional elements – LED legs, ears, and a speaker. The sketch specifies that the ears will appear on the side of the robot's head, and that the speaker will appear underneath the robot's body (possibly supported by a weight) [sketch 10/16].

By the end of this session, Dakota had added ears to the side of the robot's head. The speaker and LED legs were added during the next workshop session [workshop video and photographs, 10/16].

Session 3. Dakota's third robot sketch showed her robot as it appeared at the start of this session, with the addition of LED feet and a "booster box w/speaker" [sketch 10/23]. Both the LED feet and booster box were added to the robot during this session. The speaker was also attached [workshop video and photographs, 10/23]. As in previous sessions, Dakota evaluated several of her design ideas and made changes during building (in this case, the design of the booster box changed and the speaker was put on the table instead of underneath the robot), but she did not add anything to the robot that had not already been specified in her sketch.

Claim 2: Dakota routinely engages in the generation and evaluation of design ideas, and is effective at troubleshooting her own ideas

Evidence gathered from workshop video, field notes, and interviews all suggest that Dakota generates and evaluates her own design ideas. This sets her apart from some other workshop participants (like Allison), who were not as consistent about evaluating their own design ideas. Dakota's primary methods for evaluating ideas are prototyping and simply thinking through ideas before deciding about them, although she occasionally asks 'experts' (i.e., workshop instructors) for advice.

Session 1. We can see several instances of Dakota generating and evaluating design ideas during this session. For example, she evaluates and rejects her initial ideas about the overall design of the robot and the shape of the robot's head. She also troubleshoots some problems with the robot's tail.

As Dakota summarizes in her design journal from this session, "I had originally wanted [my robot] to be a small lizard that could camouflage itself and climb up walls..." [reflection, 10/9; see also Dakota's midpoint interview, final interview, and reflection from 10/23]. But she is forced to re-evaluate her idea when she sees that the workshop materials do not include metal (as she originally thought), and generates a new design plan to suit the materials at hand [midpoint interview]. During the final interview, Dakota describes additional reasons why her original idea would not have worked (e.g., the expense of LED's to cover the robot; final interview).

Once Dakota settles on her robot's new form she designs a hinged 2-part head [see Figure 1]. In the workshop video Dakota is seen prototyping the 2-part head, but eventually realizes that her idea is not going to work and decides to just use one part of the head [workshop video RD_c2_10-9-08]. As she explains in the final interview, "I realized that it wouldn't really work because you can't put the servo anywhere… and then I thought servos went all the way around basically so it could go open. And it really – it would have had to be in the middle and then it have to open one part and then open the other part" [final interview].

In both of these instances, the evaluation of the design idea is based upon Dakota understanding (and respecting) the constraints of the materials and resources available. In the first instance, Dakota adjusts her idea for the robot when she realizes that she will be building with craft materials (not metal), and that these materials limit the range of actions she can expect from her robot. In the second instance, Dakota's idea is altered when she learns that servos do not move they way she thought they did.

Dakota also troubleshoots problems with her robot's tail by gluing the tail back on when it falls off [workshop video RD_B3_10_9_08 and RD_c3_10-9-08], and by cutting a larger hole for the tail servo when the initial hole proves too small for adequate movement [final interview].

Session 2. Dakota engages in several instances of troubleshooting during this session. One example is when she adds ears to her robot's head. After adding the first ear, she measures the robot's head and decides that she will need to replace the front of the head to accommodate the additional ear servos [workshop video RD_a1_10-16-08; midpoint interview; reflection, 10/16/08]. A second example is Dakota's removing and re-gluing an ear that was attached backwards [workshop video RD_c2_10-16-08]. During the ear addition Dakota also cuts out two small white cups and experiments with putting them inside of the robot's head [workshop video RD_a1_10-16-08]. It is possible that with this action she is evaluating an idea about how to use the cups, but it is not clear from the video and Dakota never comments on the cups during her reflections or interviews.

An example of idea generation and evaluation can be seen with Dakota's decision not to add a tongue to her robot. Dakota's design reflection from the previous session indicated that she was thinking about adding a tongue to her robot [reflection 10/9]. However when asked about this during the final interview, Dakota reports that she changed her mind about the tongue because she realized there was no room in the robot's head for an additional motor [final interview].

Session 3. The addition of a speaker during this session provided Dakota with multiple opportunities to generate, evaluate, and troubleshoot her design ideas. She begins thinking about the speaker during session two, when the instructors introduce the speaker and Dakota asks them how heavy it is [workshop video RD_a1_10-16-08]. Then during session 3, Dakota starts to generate and explore different ideas for how to attach the speaker. She asks Meg if her initial idea (gluing the speaker inside the robot) will work [workshop video RD_a1_10-23-08]. She then generates the booster box idea, but this idea requires troubleshooting – Dakota's initial design for the booster box uses one cup, but she winds up using two cups 'to make it more stable' [final interview; workshop video RD_a1_10-23-08]. In the end, Dakota realizes that the speaker will not fit on the booster box, although the box serves another purpose [final interview].

During this session another participant (Gabrielle) adds wheels to her robot. Dakota had thought about adding wheels to her robot during the initial design session, and even takes wheels home with her to add to the robot. However, during the final interview she explains that she did not add the wheels because she deemed them inappropriate for structural reasons – she did not think two wheels would support her heavy robot [final interview].

Claim 3: Dakota's design choices are motivated by technical and expressive goals.

Dakota describes many of her robot's features in terms of their ability to enhance the robot's expressive capacity. She also makes some technically-motivated design choices.

Session 1. Dakota's decisions to add many of the robot's elements were motivated by a desire to enhance the robot's expressive capacity. For example, she describes the servo on the robot's tail as enabling different types of tail movement that can express emotion. The servo in the robot's head and the LED's in the eyes are described in similar terms [robot collage, final interview]. She also made a number of aesthetically-motivated design decisions, such as cutting out the robot's body in a unique way to produce a smooth, round shape that would look more 'natural' [midpoint interview, see also final interview, workshop video RD_c1_10-9-08, sketch 10/9].

While Dakota was conscious of the robots' aesthetic appearance, she takes some time to settle on its identity. During the first session she mostly describes her robot as a gecko or lizard, but implements elements on the robot that go against those descriptions (e.g., a dog-like tail that wags) [workshop video RD_c2_10-9-08, RD_b3_10_9_08, and RD_c3_10-9-08]. She will later refer to her robot as a hybrid 'alligator-dog' or a 'green dog' [midpoint interview]. She also describes a haphazard process for naming her robot. She initially wanted to call the robot 'robodog', but settled on 'Riley' after her mother told her to be more creative about the name [final interview]. Dakota's choices about the robot's identity and name indicate a relative lack of interest about the robot's 'persona'.

Session 2. During this session Dakota adds ears to her robot, and decides not to add a mouth. As Dakota explains in her final interview, her decision not to add a mouth is motivated by a desire to maintain the robot's expressive capacity – a mouth would have limited the range of possible emotions.

Dakota's choice to add ears to her robot during the second design session deserves some examination. The primary function of the ears is expressive – they move up and down to signal emotion [reflection 10/16, robot collage]. However, the decision to add ears encompassed a number of other motivations. Dakota states that her initial idea was to add eyebrows to her robot, but that she did not for two reasons. Her primary reason seems to be that eyebrows are inconsistent with the appearance of an 'alligator-dog'. Or as she says in her midpoint interview, "dogs really don't have eyebrows so much. They have ears, and their ears work as their eyebrows do for humans" [see also final interview, reflection 10/16]. However, in her midpoint interview she also states a secondary reasons for not adding eyebrows – she could not think of a way to make the eyebrows move up and down[14] [midpoint interview]. This explanation indicates a more technical motivation for this choice – a limitation in the type of motion that could be produced by the available actuator (a servo) may have prompted her to choose ears over eyebrows.

Session 3. Dakota adds a speaker, booster box, and LED feet to her robot during this session. She describes the addition of the speaker as an expressive choice – the speaker 'talks' to people and helps express emotion [reflection 10/23, robot collage]. The feet are described as making the robot 'walk' (virtually), and also expressing emotion [reflection 10/23, robot collage, final interview]. The booster box is described in purely structural terms – it was originally meant to house the robot's speaker, but later becomes a riser that lifts the robot off of the ground so the LED feet are visible [final interview, field notes 10/23].

Claim 4: Dakota has developed creative solutions to meet both technical and expressive goals

Dakota developed several unique design solutions for her robot. I have identified four such solutions – two that address a technical goal (moving the robot's head in a particular way, and storing a heavy element/lifting the robot off the ground), and two that address expressive goals (achieving a certain aesthetic for the robot's shape, and expressing motion without creating movement).

Session 1. Dakota develops two novel solutions to design problems during this session. The first is her method of cutting the robot's body out of a single piece of cardboard, which allows her to achieve the aesthetic goal of a smooth, rounded body for the robot [workshop video

[14] The robot's ears, which move on a servo, arc back and forth.

RD_c2_10-9-08, field notes 10/9, midpoint interview]. The second is her method for moving the robot's head. By attaching a servo to the base of the robot, she is able to move the head up and down [final interview]. This is novel because the servo itself produces a circular, arc-like motion. Dakota has invented a way of turning this circular motion into an up-and-down motion on her robot, which is a creative solution for a technical goal.

Session 3. Dakota develops two novel solutions during the third design session. First, she designs and builds a booster box to solve a technical problem – storing the speaker and rising the robot off of the ground [workshop video RD_a1_10-23-08, reflection 10/23, final interview, field notes 10/23]. She also finds a way to solve a difficult expressive problem – how to make the robot 'walk' without actually moving. Dakota's solves this problem by moving away from a literal interpretation of what it means to walk. She instead develops an abstract way of representing motion – she places two LED 'feet' on either side of the robot which can toggle on and off to simulate motion [workshop video RD_a2_10-23-08, reflection 10/23, post on messenger 10/28].

Claim 5: Dakota uses the robot as a platform for furthering her own interests

There is some (limited) evidence that Dakota uses the robot as a platform for furthering her interests. The majority of this evidence comes from programs Dakota has written and her home videos. In one home video, Dakota's robot is seen performing a presidential campaign commercial [Home video VID0037 – the workshop took place during the 2008 presidential campaign season]. In another, the robot is seen dancing to music [Home video VID0035]. Additionally in the 'Sir Dance-a-Bot' program, which Dakota says is her favorite program, the robot is seen dancing in synchrony with music. During the final interview Dakota explained that she timed the robot's movements to match the music precisely [Final interview].

Dakota has a strong interest in music [pre interview]. Her efforts to program the robot in exact synchrony to music can be interpreted as a continuation of that interest. The presidential campaign video may be interpreted as her expressing an interest in current events though the robot.

Dakota also took advantage of an opportunity to learn additional robotics information during the workshop. In design session 3, a Robot Diaries curriculum team member sought to fix some motors by setting up a soldering iron in a corner of the workshop room. Several of the participants came over to see what she was doing, but left as soon as the soldering iron stopped working. Dakota also came over to the soldering station, but unlike other participants she stayed to talk to the curriculum team member long after the soldering iron stopped working. The team member reported that Dakota was very interested in what she was doing [field notes 10/23].

Claim 6: She is confident about her abilities as a builder/engineer

Evidence gathered from pre-post surveys, interviews, and workshop video suggest that Dakota was confident about her ability to design and build robots.

At the start of the workshop, Dakota reported her level of confidence to design and build robots as moderately high (3.67 out of 5). At the conclusion of the workshop, her confidence rating was high (5 out of 5). Evidence that Dakota felt confident in her technical abilities can also be seen in her behavior during the workshop, and in her interview responses. For example, during the first robot design session Dakota took responsibility for installing the workshop software on her home computer (participants' parents usually took on this responsibility) [workshop video RD_B2_10_9_08]. Dakota also indicates numerous times during her midpoint and final interviews that she felt confident in her abilities while designing and building her robot. This confidence is well illustrated by an excerpt from her midpoint interview:

> Researcher: So if somebody looked at the robot you built, what do you think they could tell about you?
> Dakota: About me?
> R: Uh huh. About the builder, about the creator.
> D: Um, that I really didn't know what I was thinking of as the animal at first because usually you don't have green dogs.
> R: {laugh}
> D: *And I think also that I can figure out things logically pretty well like the shape of the base of the robot that I cut out and then like the ears moving and stuff like that.*
> [midpoint interview]

3.5 ALLISON

3.5.1 Workshop Engagement

Allison was 10 years, 10 months old at the start of the workshop. Her interests include writing (she has written her own novel), theater, and a variety of arts and crafts projects (e.g., sewing). When asked why she signed up for the Arts and Bots workshop, she said that making the different emotions sounded like fun, and she'd never built a robot before [pre interview]. According to her mother Allison has had some basic experience building circuits and using motors and lights often in the context of craft projects. Allison's mother had offered her daughter the opportunity to use Lego Mindstorms, but Allison was not interested [parent pre interview]. Allison's mother estimated that her daughter spent between three and four hours a week working on her robot at home [parent final interview].

3.5.1.1 Robot Design Session #1

Sketch. Figure 9 shows Allison's sketch from the first robot design session.

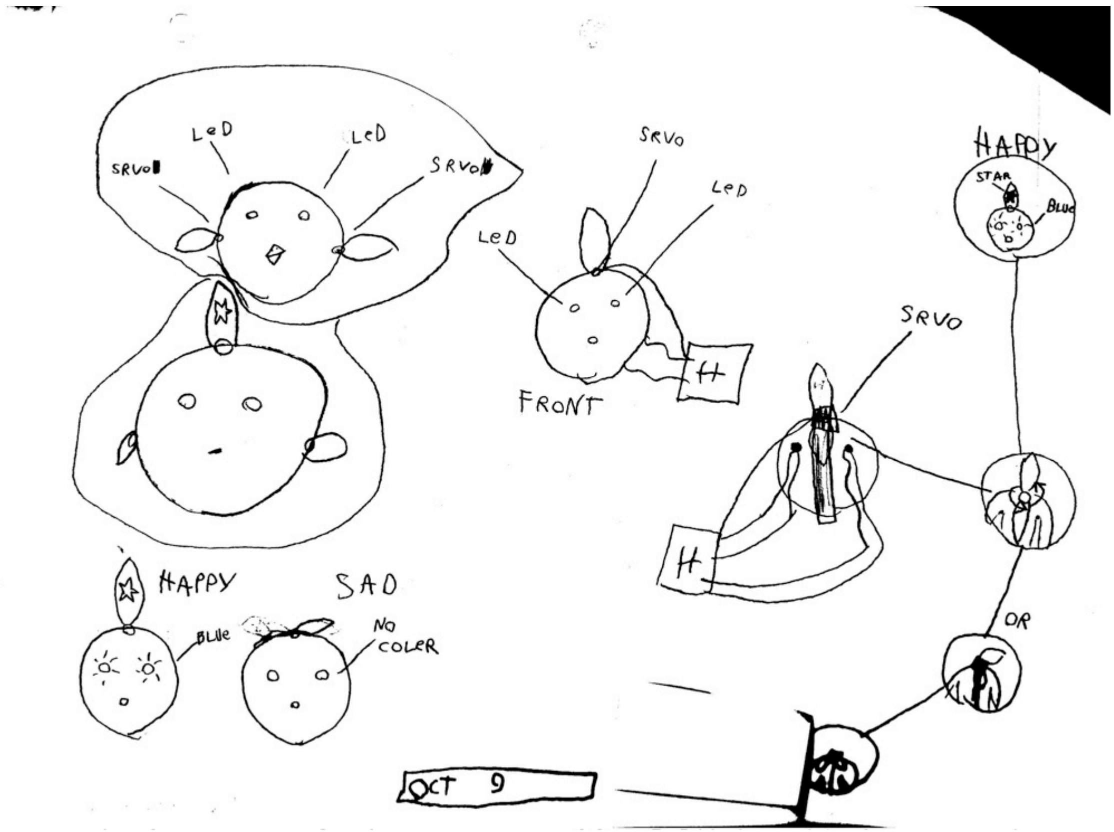

Figure 9. Allison's sketch from design session #1

Allison's initial sketch describes the front and back of a circular robot in the form of a bird (later named 'Lily'). The robot is designed to have 2 LED eyes, a wing on either side of the head, and an additional appendage – a feather – on the top of the head. According to the labels provided in the sketch, the feather and each wing will be controlled by its own servo (spelled "srvo"), for a total of 3 servos. The sketch also shows that each LED and the servo controlling the feather will be attached to the Hummingbird, a processor board (labeled in the sketch with the letter 'H').

This sketch also lays out how Allison intends to display emotion on her robot. On the left side of the sketch we can see what the robot will look like when it's happy (star up, blue eyes) and sad (star down, no color in the eyes). The movement of the top feather is also represented by the diagram chain on the right side of the sketch. These diagrams both represent what the robot will look like while expressing different emotions, and identify the eyes and feather as the robot's primary expressive elements. During the workshop, Allison explained her sketch to Mia (another participant) in the following way:

> [holding her sketch] Look, I'm making this little bird, and this flips over, and the star means it's happy and the lights light up. When it's sad, they both go sideways and there's no color. [Allison puts down her sketch and demonstrates the feather spinning around]. So it like flips, the motor makes it flip. I'm also going to do embarrassed, or bashful, or something. [workshop video, RD_c1_10_9_08]

By the end of the first design session, Allison's robot approximates her sketch in a number of ways. Her robot has a round body, two eyes made out of tri-color LED's, and two of the three appendages described in her sketch – a feather (with a star on the top of it's head) and a wing on one side (she adds the other wing later), as well as a small drawn-on mouth. Allison's robot also had a Styrofoam ball over each eye (not shown in picture). Allison has incorporated all 4 pieces of technology provided at the start of the workshop (2 tri-color LED's and two servos) into her robot. During this session, Allison also added a cardboard stand to the back of her robot, so that it would balance and stand up on its own (see Figure 10).

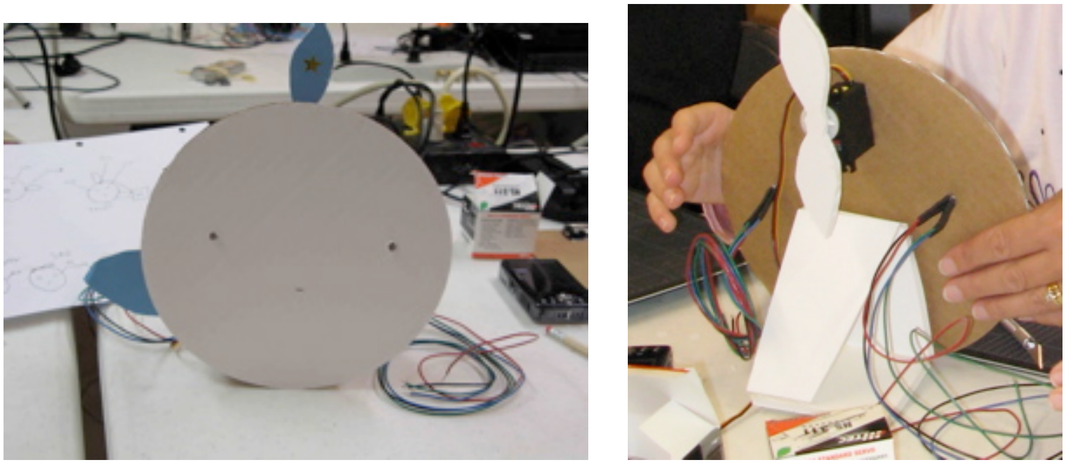

Figure 10. Images of Allison's robot from design session #1

Build. The body of Allison's robot is made out of a cardboard cake circle. Her major building tasks for this session were adding LED eyes, cutting out and attaching the two appendages (wing and feather), and building a stand for the robot.

Allison initially had difficulty figuring out how to attach the robot's top feather. When Meg approaches Allison to offer assistance, Allison tells Meg that she will need to start over because she cannot figure out how to attach the servo in a way that will enable the feather to spin the way she wants it (with half of it always hidden behind the robot). Meg suggests a solution – gluing the servo onto the back of the robot's body, facing out, so that the wing can spin freely while remaining half hidden. Allison is satisfied and adopts this solution [workshop video RD_c2_10_9_08].

As she explains in her final interview, Allison clearly intended the feather as an expressive element for her robot.

> R: What are the different ways that your robot can express emotion?
> Allison [A]: It can move its arm and it can twitch its feather. Sort of like you know… how your face expressions sort of change or your eyebrows when you're feeling differently, even if you're not trying to they just sort of change. So it's feather change since it doesn't have any eyebrows.
> [final interview]

In her design journal, Allison commented that her biggest challenge during this session was getting her robot to stand up [reflection 10/9; she also discusses this during the final interview]. The goal of making the robots stand up was explicitly stated by the workshop instructors at the beginning of the session, and at numerous points during the session. They reminded the participants that the main building material for the robots (foam board – roughly ¼ of an inch thick) was thin and would not stand up on its own, so the girls would have to devise ways of making their robots stand up. Allison's solution to this problem was to build a stand on the back of the robot (see Figure 10). A review of workshop video suggests that this solution was devised and implemented with much assistance from Meg and Carol:

> After discussing how to attach her feather, Meg reminds Allison that she needs to figure out a way for the robot to stand up, and Allison says she is going to add a support to the back of her robot. Meg suggests that Allison use a piece of foam board for the support. Allison gets a long piece of foam board (longer than the height of her robot), cuts it a bit to make it thinner, and holds it up at an angle to the back of her robot. Allison plays around with her support a bit, and then places it directly underneath the robot body. With the robot sitting on top of the strip of foam board, Allison comments to herself, "I'll just hot glue this on the end… I solved my support problem, yay!" She then moves the support out of her way and continues working on other aspects of her robot. She asks for Carol's help in making holes for the LED's, and then attaches them.
>
> Allison calls Carol back again to ask for help attaching the feather. Carol suggests using either tape or hot glue to attach the servo, and reminds Allison that she will need to figure out how to make her robot stand up. Allison responds by telling Carol she is going to hot glue her robot to its stand. Carol suggests that this might not hold the robot up. Allison responds by saying she will do what Carol suggested to the class earlier in the session – she will build a triangle to support the robot. Carol and Allison spend the next few minutes working together to build the triangle base for the robot – Carol first builds a demonstration triangle, and then encourages Allison to build her own. While Allison is building, Carol remains at her side to offer additional help and support. Once Allison has finished building her own triangle out of foam board, Carol helps Allison figure out how to attach it so that the robot will stand at the desired angle. Allison then attaches the triangle and the feather servo to the robot using hot glue.
>
> Upon returning to her seat, Allison discovers that the stand is not working. She asks Carol, "what do you do if it still falls over?" Carol looks at the robot, and suggests to Allison that the robot is not balancing because she just added something heavy to it (a servo for the feather): "So here's what to think about. Here's where the base is, and here's where all the weight is… we just need to have a bigger triangle." Carol then

proceeds to build a larger triangle for Allison's robot, and attaches it for her. Upon returning to her seat with the new base, Allison exclaims, "Oh, it's done!"[workshop video, RD_c2_10_9_08]

The balance issue comes up again later in this design session, after Allison adds a wing to the left side of her robot. The addition of another heavy servo once again throws off the balance of her robot, which now rolls to the left. When this happens, Allison is able to tell Carol the reason – because the wing weighted it down – and Carol suggests weighting down the stand to stop the robot from rolling [workshop video RD_c2_10_9_08].

During this session Allison also develops an aesthetic for her robot, which she describes in later interviews as 'minimalist', 'Japanese', and 'cute'.

R: What's your favorite thing about the robot that you've built?
Allison: The fact that it's cute
R: What do you think is the cutest thing about it?
A: Its eyes, and the way it looks sort of… I don't know, it just looks very Japanese and I like Japanese art. It has the big eyes and the small mouth and the big head.
[midpoint interview; she also describes the robot's Japanese aesthetic in the final interview]

However, in describing the origin of her ideas Allison admits that the Japanese aesthetic wasn't always her intention. Rather, she was inspired by the examples on a curriculum handout, and that seems to have led to some of her design ideas[15].

R: Where did your original idea come from?
A: I don't know. I was looking at the sheet and I saw some very circular inspired robots and I thought oh, that would be cute. So I decided to make a very simple bird 'cause I don't really like a lot of things. I like very simple things.
[final interview]

The simple or 'minimalist' aesthetic expressed in Allison's robot is a familiar style to her.

R: So if somebody looked at the robot you built, what do you think they could tell about you, the creator?

[15] In the final interview, Allison's mother points out another potential source of aesthetic inspiration for Allison's robot – the 'Littlest Pet Shop' dolls that Allison collects all have large heads with big eyes and a small mouth [parent final interview].

A: I don't know. I might have a very specific style, cause the way I built my robot was the way I build a lot of other things. They're very simple, with not too much detail. Except that surprises me because when I make other things, they have lots of detail. Some things I like detail with and some things I don't.
[midpoint interview]

During the final interview, Allison explained that often when she paints she likes to have minimalist paintings, where you "do just one thing that's very pretty and you leave it like that… or like flowy or something. Something that will catch your eye without being really big." Allison also described some of the choices she had made to maintain the robot's aesthetic, such as adding Styrofoam eyes because she thought they "looked so cute" on someone else's robot, and felt they would make her robot's eyes bigger and less bright. Allison also described some choices she had made not to add features that she felt were inconsistent with her vision.

A: Well you get to choose what it – what you want it to do, and you get to design that, and choose what looks best on your robot if you have 2 design choices. One that might look really good on I don't know, Noel's [another participant] robot but terrible on mine.
R: Is there something specific that you've thought of putting on your robot that you thought would look good on somebody else's but not on yours?
A: Well eyebrows. Mine would look terrible with eyebrows because it was sort of – it looks Japanese. Because it has the big eyes and the small beak. And eyebrows would make it look more American… but Mia's [another participant] dog looks excellent with eyebrows.
[midpoint interview]

Interestingly, Allison seems to associate her robot's aesthetic with a particularly girl-centered approach to robotics.

R: How about actually building the robot, was it easier or harder than you thought it would be?
A: it was sort of satisfying… because I don't know many kids who build robots… if they are kids they're mostly boys.
R: Ah. So you don't know a lot of girls who build robots.
A: No.
R: Okay.
A: That's because usually when you build a robot it's all steel. Steel looking. And they're never cute or whimsical. I think Lily [her robot] looks whimsical.
…
R: What kind of workshop would you sign up for [in the future]?

> A: I don't know, a group of people and a, like building out of sort of more crafty stuff. But building a robot out of metal would be fun, if I could make it look sort of crafty.
> R: Yeah
> A: if it was interesting metal… like if it was interesting colors or something.
> [final interview]

Program. Allison programs several expressions for her robot, including 'angry' (star flipped down and red eyes) and 'bashful' (purple eyes) [field notes, 10/9/08]. Allison also programs a sequence of movements called 'dance party,' which utilizes the lights and both servos. During the group charades activity, Allison is assigned to make the expression 'ashamed'. She programs her robot to flash purple eyes with the feather hidden.

While Allison seems to use the feather as an expressive element during this first workshop session, she comments in her final interview that her initial plan to use the feather and star as expressive elements did not work out as she had hoped:

> Well, at first I thought the servo could turn all the way around so it was going to have a star on one side. (And then it could to the not star *?difficult to hear*) [points to left side of sketch]. But since it can't, the star's always up. [final interview]

At Home. The side wing Allison added to her robot fell off at home. However, as an e-mail message from her mother suggests, she was able to glue it back on with a minimum of fuss:

> Wow! I am so amazed by the confidence Allison gained after her first day of really working with the robot. She was completely comfortable as she showed it to her dad and to some visiting friends - she kept her cool and reglued the wing (in order to fix it, she needed to take some things loose from the hummingbird and put them back - which she did effortlessly). As soon as she got home, she immediately jumped into trying to figure out another emotion to add to her list.
>
> I knew intellectually that the focus of the class (storytelling/emotions/relationship) would be a good fit to get Allison interested in the work - but it has really surpassed my expectations.
>
> I can't wait to see her after the rest of the classes!
> [e-mail message from Allison's mother to researcher, 10/10/08]

Allison uses her camera to shoot several videos at home. In one video she shows that her robot will live in a large room on the first floor of the family's house. The video then pans to the robot, and Allison says "ever since Lily arrived she's been very happy [robot turns on and assumes a happy pose – blue eyes and the feather up]. Happy, happy, happy. And she's also having a great time. This is something she's been having fun doing [robot begins dancing to music, with its eyes flashing different colors and the wing and feather moving quickly back and forth]. And that was my video" [home video VID0003.mov]. Allison also uses the camera to shoot a number of unrelated family activities, often introducing the video by saying "this is Allison at the [last name] household" or "this is Allison from the Allison channel."

Allison posted several programs on the messaging site, including 'dance party', 'angry', 'sleepy', 'bored', 'cha cha', and 'sick'. The 'sleepy', 'bored', and 'cha cha' programs were posted with accompanying text:

> Lilly got up early to study for the spelling bee She was very sleepy. And bored. But all her hard work paid off because she won the spelling bee and she was really, really happy, [messenger 10/14]

The 'sick' program was posted with text that read 'seriously, I'm not feeling so good......' [messenger 10/14].

3.5.1.2 Robot Design Session #2

Sketch. Figure 11 shows second robot sketch, made at the start of the second robot design session.

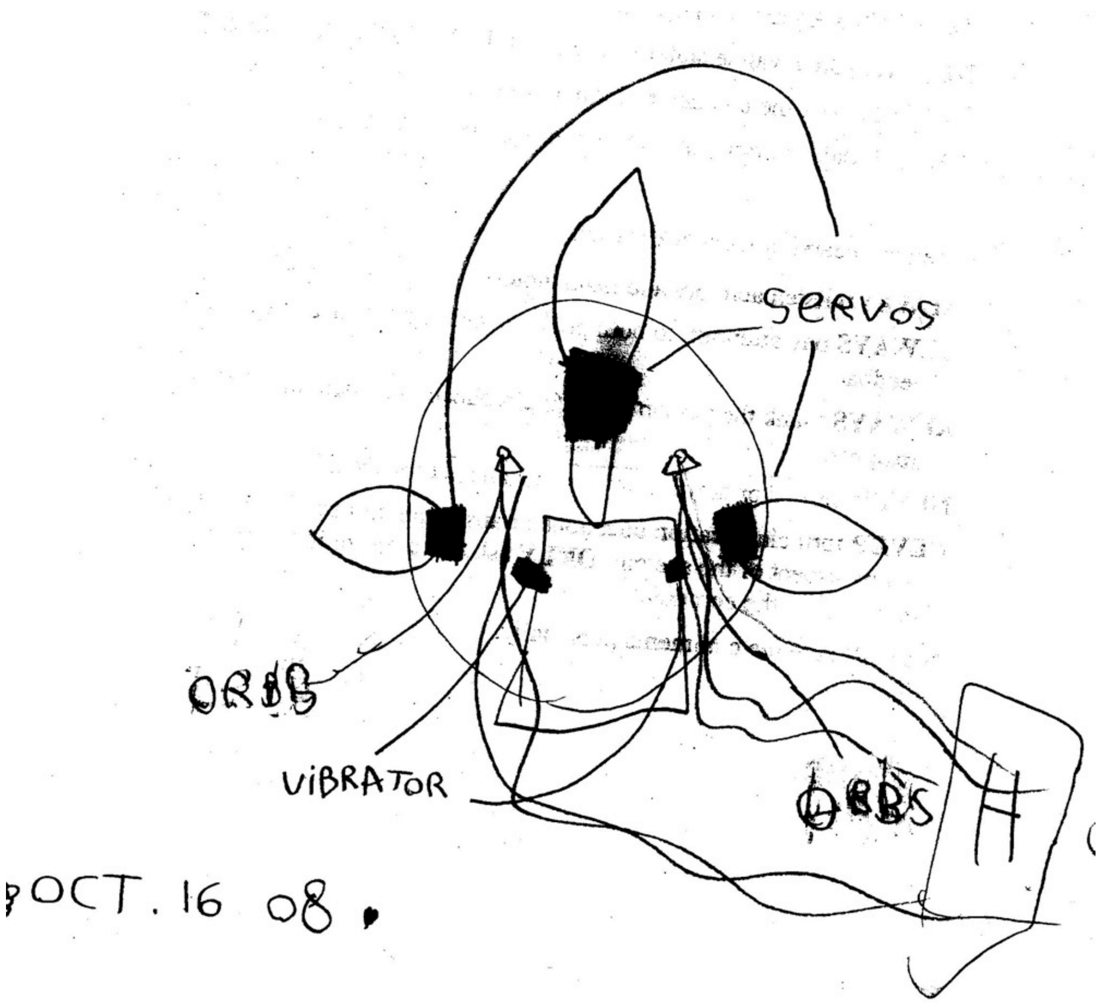

Figure 11. Allison's sketch from design session #2

This appears to be a sketch of the back of Allison's robot (during the sketching activity, Allison was looking at the back of her robot; workshop video RD_a1_10_16_08). This sketch includes the robot's 3 appendages (two wings + a feather on top), all of which are controlled by servos. As in her first sketch Allison has labeled the Hummingbird and both lights ('orbs' are another name for the tri-colored LED's). This sketch includes the stand Allison added to the back of her robot in the first session (the stand is drawn as a rectangle between the wings). The new addition in this sketch is the two vibration motors (labeled 'vibrator'), attached on both the left and right sides of the robot's stand.

By the end of this session, Allison has added an additional wing, two vibration motors, and a speaker to her robot (see Figure 12).

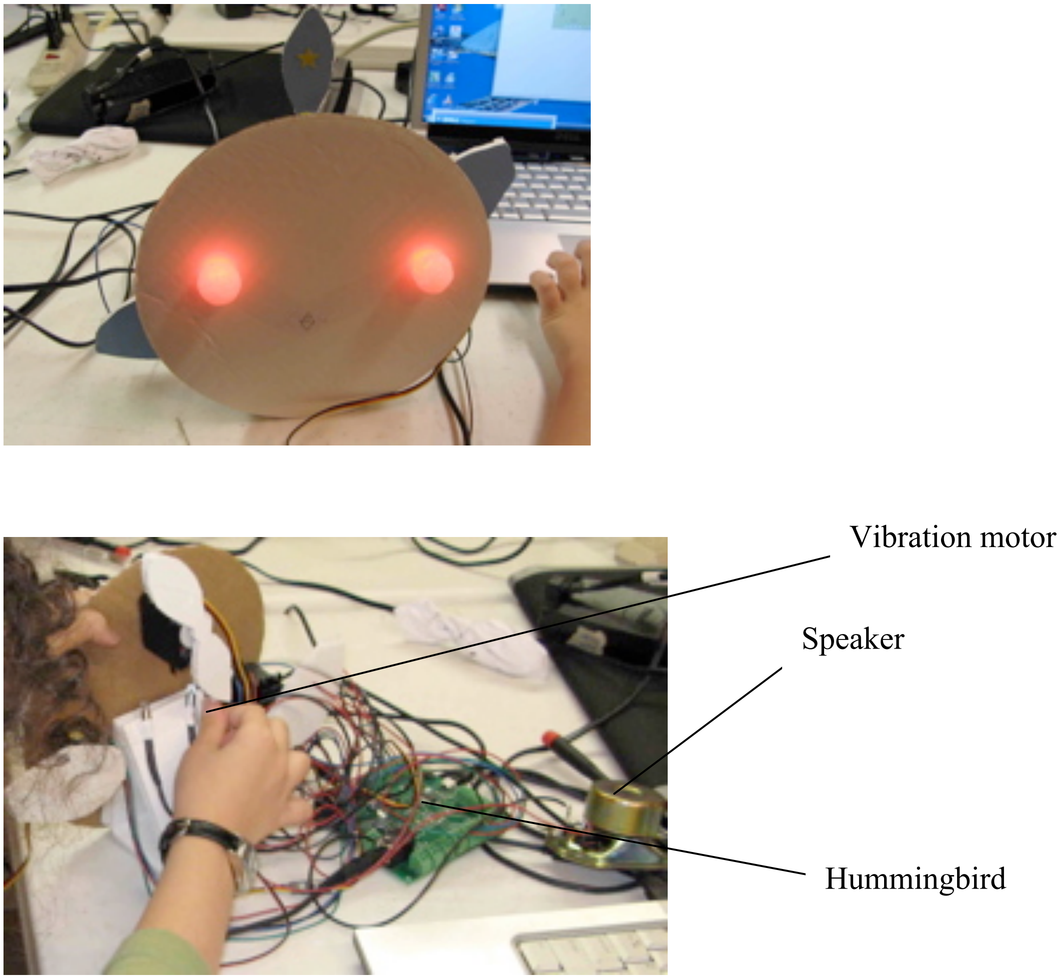

Figure 12. Images of Allison's robot from design session #2

Build. Allison acquires two vibration motors from Meg and attaches them to the back of her robot with electrical tape. As she explains in her midpoint interview, the purpose of adding the vibration motors was to make the robot more expressive:

> R: Can you tell me what you changed on your robot last week?
> A: I gave it another wing…I also put 2 vibrators on that can make a very angry sound. It can also sort of make it vibrate, a little...
> R: Can you tell me why you decided to make those changes?
> A: …It doesn't have a lot of angry qualities – it's so cute.
> R: Okay. And you wanted it to be more angry?

A: Yeah, so it could be frustrated or overwhelmed, or hysterical…. And the other wing just helps with the expression and the realistic-ness of it.
[midpoint interview; see also workshop video RD_a1_10_16_08 – Allison stated her intention to put in a vibrator so the robot could shake when it was angry]

After adding the vibration motors, Allison works on the robot's second wing. Allison's intention in adding the second wing was partially to make the robot balance [she states this intention during a group discussion prior to building; workshop video RD_a1_10_16_08]. The lack of balance created by the single wing had already caused some problems for this robot, prompting Allison's mother to develop a creative solution at home – putting pennies on a piece of paper and crumbling it up to make a weight [midpoint interview].

To make the wing, Allison cuts it out of foam board and then asks for Meg's help in finding the center of the servo's range of motion. She pauses, prompting Meg to ask if she needs help (Allison replies, "I just like making sure I'm thinking this through before I hot glue"), then resumes her work and glues the wing onto the servo and the servo on to the robot's body. When she is finished she comments to Dakota, "my bird finally has two wings" [workshop video RD_a1_10_16_08].

Once the second wing is glued on, Meg returns to Allison's work area and asks her if she has tested out her vibration motors yet (she had not). Allison then attaches the motors to the Hummingbird. While she is working she comments, "when I thought about building robots, I thought it'd be much harder. It's actually pretty easy, if you know what to do" [workshop video RD_a1_10_16_08].

With the components plugged in, Allison tests out the new wing and discovers that it does not move where she wanted it (instead of moving up and down on the side of the robot, it is moving behind the robot). Meg tries to help Allison think about the servo's range of motion, and suggests that she re-attach the servo. Allison then removes the wing servo and re-glues it into a new position. Once glued, Allison returns to her computer and tries it out again. Allison also discovers another problem with the wing – she made it by tracing the shape of the first wing, but did not realize that this would result in the wing being backwards [midpoint interview]. But as she explains to Meg during the session, "it's a little awkward but I still like it. The wings are both different ways. They're shaped differently because I forgot that if I traced that one it would be opposite. But I don't really care. I think, it looks expressive" [workshop video RD_a1_10_16_08, RD 10-16-08d3].

During her mid-point interview (which followed this design session), Allison commented about some of the functional challenges she has encountered while designing her robot. When asked what she felt most confident doing in the workshop, she replied, "designing… and beginning to build." When asked to explain, she continued:

> A: Well later it gets sort of complicated because you have all this stuff and you need to make them compatible and the wings are falling off. Um, so that's why it's kind of difficult to be at the middle of it when you're not really sure what to add next.
> R: Oh ok, so what do you mean by 'make them compatible?'
> A: Like, so the servos don't collide. So nothing collides with each other on the back and how little room I have on the back and how to make it stable.
> [midpoint interview]

Once she has the components plugged in, Allison also tries out her vibration motors. She moves the motors around, pulling them off of the robot and then re-taping them back on, but in general seems pleased with the extent to which they vibrated her robot (even though she takes them off a few weeks later because she felt they were ineffective). At one point she has a conversation with Meg about whether the motors should actually touch the cardboard of her robot. Meg suggests she might get more movement if they do, but Allison counters by remembering that the last time she used vibration motors, the vibration motors got stuck when they touched the cardboard, making that strategy ineffective [workshop video RD_a1_10_16_08, RD 10-16-08d3].

Allison's final addition during this session is the speaker. Earlier in the session, Allison commented that the speaker would not fit on the back of her robot because she does not have enough room [workshop video RD_a1_10_16_08]. She now attaches the speaker and puts it down on the table, next to the robot [workshop video RD_a2_10_16_08]. Allison's comment to another participant during the early part of the session indicated that she was thinking about the speaker as an expressive element – when she hears a 'mooooo' sound effect she suggests using it to display anger [workshop video RD_a1_10_16_08].

Program. With the speaker attached, Allison gets excited about a particular sound effect – a bird-like chirp. According to field notes taken during this session, Allison was so excited about the chirping sound effect that she asked a curriculum team member how she could make it chirp repeatedly [EH field notes 10/16]. Both of the expressions she created for her robot during this session ('hysterical' and 'frustrated') included this chirp. When she displays the 'hysterical' program Allison explains that the tweets are supposed to be the robot crying. One of the other workshop participants tells Allison that there is a crying sound effect available to them, but Allison replies that it sounds like a baby crying, which is the wrong kind of crying for her robot [workshop video RD_a2_10_16_08].

When asked how her robot expresses emotion, Allison comments that the robot's eyes, arms, and feather are all important expressive elements. For example, pale green eyes and drooping arms can make the robot look sick, while putting the robot's feather straight up can make it look excited [midpoint interview]. Allison also commented that when she programs emotions for her robot, she often thinks about what the emotion would look like on a person (or in some cases, a bird):

> A: I think about what it looks on a person, what an emotion would look like on a person, but I think it's how I feel. Cause this robot expresses almost everything it feels in some little way, unlike I do. But I can think of the way I feel or sometimes the way I move or stuff or act when I'm really really angry… so I think about really what a person would do, and then I try to make the robot look like it's doing that. An interesting theory is that if there was a world where everyone showed what they thought and a person from that world came to Earth, all of the earth people wouldn't like that person because they showed everything that they thought… because a lot of time we don't really – if we have a bad thought we don't ever say it. We keep it in. Some people keep it – I know I try to keep it in, but it would look unusual so I'm making my robot kind of like that
> R: Like what?
> A: Like very expressive of what it's thinking.
> …
> A: Since excited… its feather goes straight up. It's kind of like um [the instructor's cockatiel]. Every time it gets excited or like surprised, its feather on the top of its head sticks up. Cockatiels do, so it looks kinda like a cockatiel.
> [midpoint interview]

Allison also expressed some of her ideas about future programs during the midpoint interview, for example having the robot dance to her saxophone (midpoint interview; parent midpoint interview). However, she later realizes that her plan, which was to have the robot recognize and respond to individual notes, was not realistic because she did not have a sound sensor. She also expressed doubt that the robot would ever be able to recognize the different notes (final interview).

3.5.1.3 Robot Design Session #3

Sketch. Figure 13 shows Allison's third robot sketch, made at the start of the third robot design session.

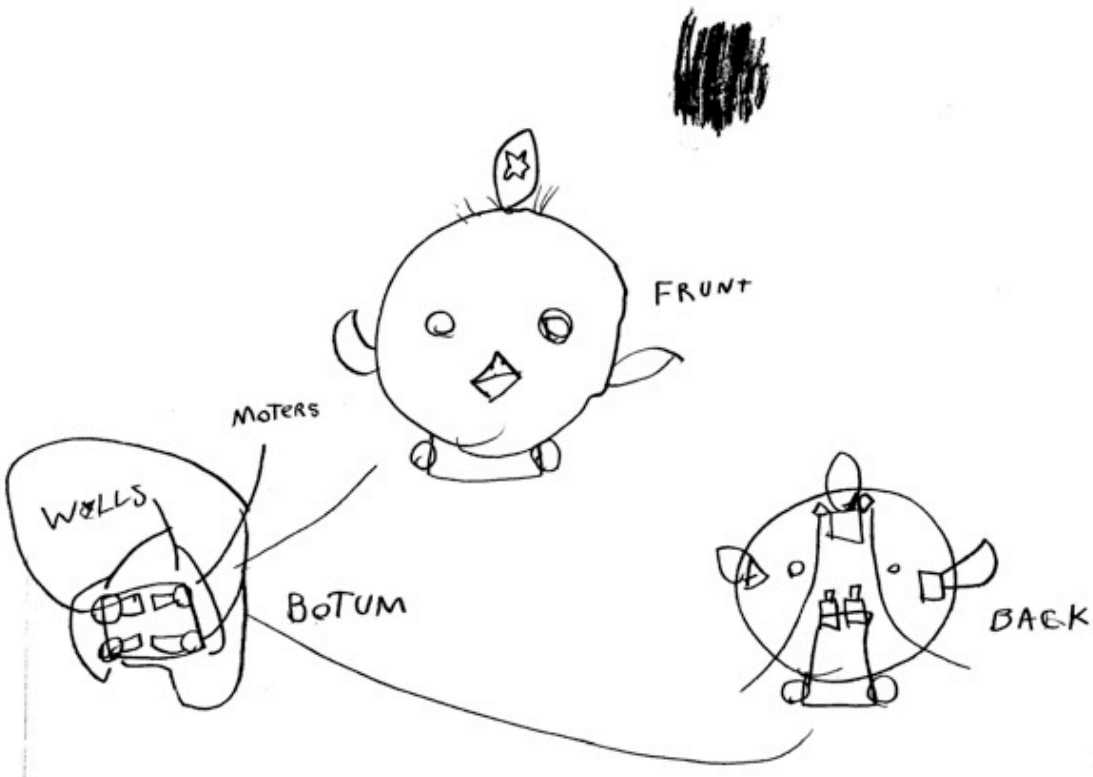

Figure 13. Allison's sketch from design session #3

This sketch shows front and back views of the robot, as well as a view from the bottom. All three appendages are represented on this sketch (2 wings + feather with star), as are the robots eyes and its stand. The little boxes on top of the stand on the 'back' sketch may be the vibration motors. The new features here are the wheels and motors, most clearly marked on the bottom sketch. There appear to be 4 wheels drawn in a box. It is interesting to note that another participant (Gabrielle, age 13, who sat near Allison at the workshop) also decides to add wheels during this workshop session.

Figure 14 shows the robot's new base, a new location for one vibration motor (the other has been removed), and two LED's on the base. The first photo (front) was taken during the third design session. The second photo (back) was taken by Allison and/or her mother in the week following the third design session, in response to a request from the researchers (a photo was needed for a collage assignment).

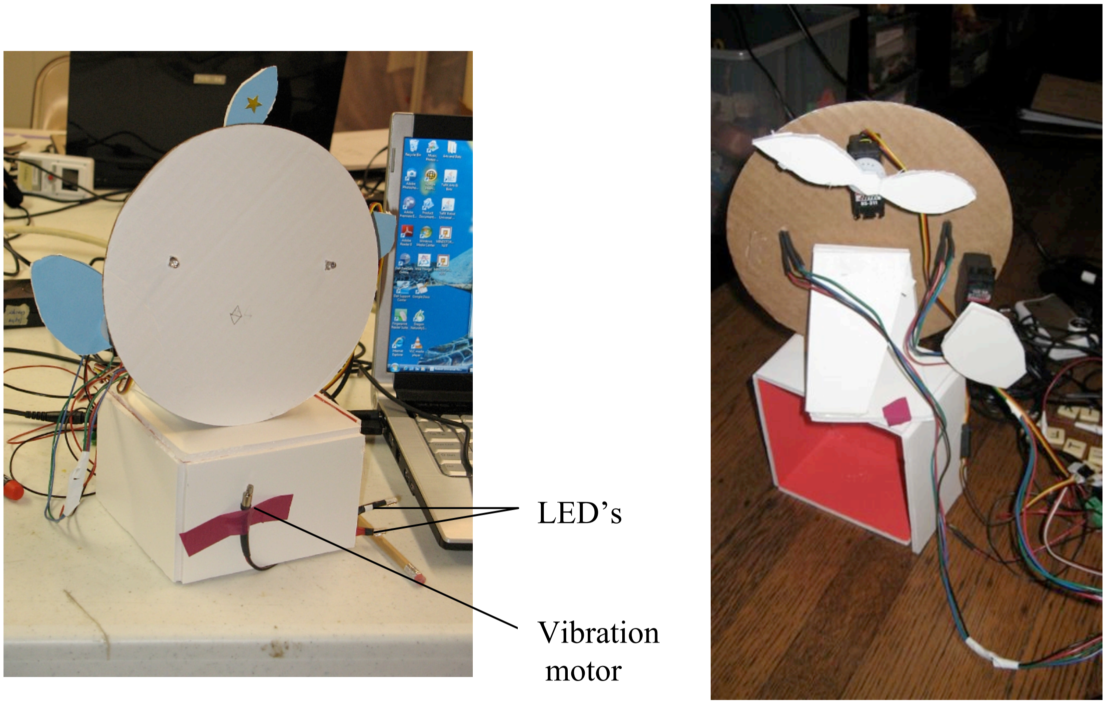

Figure 14. Images of Allison’s robot from design session #3

Build. While unpacking her robot at the start of the workshop session, Allison comments, “the wires are half the problem. The hardest part about setting up a robot is how much wires you have” [RD_b1_10-23-08.mov]. This comment foreshadows Allison’s later act of unplugging all of the robot’s wires and re-attaching them in a more orderly fashion.

Allison acquires and attaches some LED’s to her robot early in the session. She hooks them up to the hummingbird, turns them on and off, and tapes one to the back of her robot near the feather [workshop video RD_b1_10-23-08.mov]. Later in the session, Allison moves the LED’s on to the box below the robot.

It is not entirely clear where Allison’s ideas to add wheels to her robot originated. During her midpoint interview she comments, “ it would be kind of cool if [my robot] could like walk or something. Like roll on wheels," so it is possible that she came up with this idea on her own. This idea also could have been influenced by other participants (e.g., Gabrielle's addition of wheels). It is worth noting that during the sketching phase, Allison may have overheard Gabrielle's conversation with Meg (and later conversations with Carol) about her plan to add wheels to a box, and then attaching the box to her robot in order to make it move [workshop video RD_b1_10-23-08.mov]. About an hour into the workshop session, Allison has the following conversation with a Robot Diaries curriculum team member:

> Allison: I'm building a storage case for the hummingbird so mine can roll around. So I have to disconnect everything.
> Curriculum team member [CT]: How's it gonna move around?
> A: with. I'm gonna make motorized wheels, once I get, when I get 4 motors I'm gonna, motorized wheels. So now I'm just, I have to disconnect everything.[16]
> CT: the board can only do up to 2 [motors]. So you won't be able to have 4
> A: [inaudible, but sounds like a sentiment of disappointment]
> CT: So you have to [inaudible]
> Chloe [another participant]: You've got one more servo, don't you?
> A: How can it only do up to 2?
> CT: That's all it has space for
> A: Oh, let's think. [silent for a little while] ah hah. I'll have little blocks that are almost, that almost go to the ground, so they support it when it stops. So they can sort of brush the ground so the wheels are on either side of the [inaudible], and it will just go forward.
> [workshop video, RD_b1_10-23-08.mov]

This conversation is a turning point for Allison, where she realizes that her initial plan of adding four wheels to the robot is not going to work. Following this conversation Allison disconnects all of the technology from her hummingbird, and then gathers a sheet of foam board and exacto knife and goes off to cut something out [workshop video RD_b1_10-23-08]. She is off camera while she is cutting, but during that time she interacts with the workshop instructors. Carol offers her a straight edge to facilitate cutting, offers her help, and eventually winds up cutting out parts for Allison's box [field notes 10/23].

[16] Each wheel needs to be attached to a separate motor.

While Carol is cutting, Allison tries to acquire motors from Meg. However, there is a problem with some of the motors – the wires have started falling off, so one of the curriculum team members takes out a soldering kit and tries to solder them back on (as it turns out, the soldering iron is faulty so she is not able to do this). Soon after, Allison comments that 'it's gonna take a long time,' and explains that when Carol is finished cutting out a structure for her she will have to put it on, re-check all the wires, and deal with the wheels [RD_b1_10-23-08.mov].

Once Carol finishes cutting out the box, she and Allison have a brief conversation about exactly where the wheels will go (Allison wants to put them on the bottom, Carol suggests putting them through a hole in the box) [RD_b1_10-23-08.mov]. However, a little later Carol and Meg follow up with Allison to let her know the motors cannot be fixed that day. Allison responds, "that's okay. I'm not gonna do the motors. I decided not to," and later tells Meg that she's not going to use the motors because she's running low on time. In the final interview, Allison explains:

> [I] could never really get the right spark to do it so I don't think it was my best idea… Like I didn't really have the inspiration to-, or really wanting to do. I just thought well I guess it might be-, look-, it might be cool if it could move but then it ended up just looking better if it didn't move. But I never really had the inspiration to actually make it work. [final interview]

Instead, she spends the remainder of the session re-attaching components to the hummingbird, organizing and re-attaching her wires (she tapes the relevant wires together with white tape), and tapes the vibration motor and LED's to the front of the robot. During an interview, Allison comments that "getting all the wires set up right" was one of the things she was least confident doing in the class [final interview].

At the end of the session, before the Show and Tell activity, Allison tells Meg, “I don’t have much to show. I didn’t add much, I didn’t really add anything new… I thought about the, I just improved the structure.” While demonstrating her robot during show and tell, she comments on the lights and the vibration motors. Regarding the LED’s, Allison says, “if I had made holes in it then it could have like a box that could sort of dance, with all the lights” [RD_b2_10-23-08.mov]. (This idea could be a reference to Dakota’s successful addition of LED’s on the bottom of her robot to simulate movement). Allison believes the vibration motors will be so powerful in vibrating her robot that she wants to tape the robot to the table. The vibration motor does not actually move the box, although Allison comments that it ‘still makes a nice [angry] sound’ [workshop video RD_b2_10-23-08.mov]. In the final interview she states that the vibration motor never made the robot vibrate because it got stuck when it hit the cardboard [final interview]. Allison wanted to re-attach the speaker during show and tell, but she runs out of time to do so [workshop video RD_b2_10-23-08].

It is interesting to note that while the box was never used for its intended purpose (to hold the wheels), Allison has re-purposed it as a ‘nest’ for Lily which holds the hummingbird (this was Allison’s mother’s idea) [final interview]. Allison also saw the box as a useful resolution to the balance problems that she had struggled with during earlier design sessions:

R: What was the hardest part of the workshop, like the hardest thing to do?
A: Make it balance.
R: Make your robot balance?
A: Yes, [inaudible]
R: So why do you think that was such a challenge with this particular robot?
A: Um, it’s very light in the front and heavy in the back.
R: Heavy in the back.
A: Because, okay it has the hummingbird. And those servos, and those servos are heavy.
R: Yeah that’s true.
A: I guess the hummingbird isn’t very heavy but all the wires are sort of leaning. So the wires put together can be very heavy.
R: Yeah, I can see that.

A: It was lots less balanced without-, without the box.
[final interview]

At Home. At home Allison participated in a group story by posting a program called 'pleased' for her robot.

3.5.1.4 Additional Changes

Following the introduction of sensors during the next workshop session, Allison adds a motion sensor to her robot and, while at home, programs the robot to say 'trick or treat' when someone approaches [home video VID0025 demonstrates the robot saying 'trick or treat' and being given a piece of candy]. As can be seen in Figure 15, the robot is also dressed up for Halloween with a mask and a trick-or-treat bag for collecting candy.

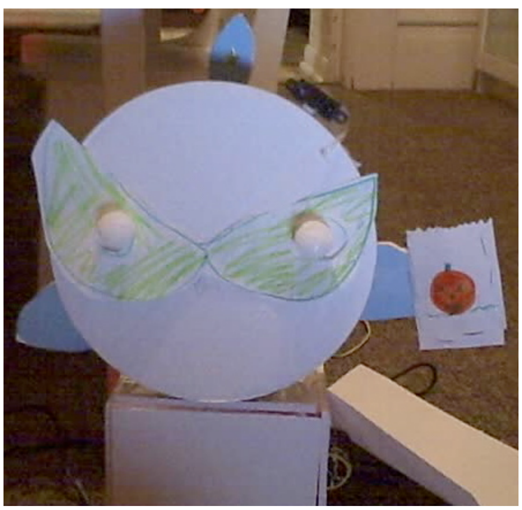

Figure 15. Allison's robot dressed up for Halloween

During her final interview, Allison also articulates her plans for building a second robot [Allison also mentions wanting to build a second robot during an in-class interview, VID0003]. The second robot, named Daisy, will interact with Lily by doing 'little scenes' such as being afraid of the dark and dancing:

> You know how some kids are afraid of the dark? I was going to make the lights turn on (2x). [and Daisy] like start tweeting wildly… Like Lily would disconnect a circuit and the light bulb will go out and the bird would start tweeting [something inaudible 11:32] and her eyes will turn red and her feather would droop [I moves feather to one side], like-. And then um, um she would, re connect the circuit… it was just a joke on how sometimes very young kids are afraid of the dark, because [Daisy is] supposed to be a baby. [final interview]

> I was going to make a dance sequence so Lily's was trying to dance and there was music and the little bird would come in and go tweet and she'd go urrr. Tweet. Because siblings, younger siblings can kind of be annoying sometimes. [final interview]

Allison also explains that she has named the baby bird Daisy because, "I sort of imagined personalities, like Lily's is sort of very expressive and Daisy's is sort of wandery. As most babies are" [final interview].

At the final interview Allison shows the researcher how she and her mother have already started working on the new robot. However, Allison's mother did not respond to the researcher's request for a follow-up interview so it is not possible to say if they completed this plan.

3.5.2 Summary of Evidence

Allison engages with the Robot Diaries workshop primarily as an artist. She does develop building plans for her robot, but often uses those plans as a launching point rather than as a strict guide for building. Allison seems primarily interested in achieving expressive goals with her robot, and develops creative solutions as a means of meeting some of these goals. Allison also treats her robot as a representation of herself or of the character Lily.

This characterization of Allison as primarily interested in the artistic aspects of the workshop is consistent with her mother's description of her interests, both before and during the workshop:

> So, if she wants a little skull whose eyes light up, she's willing to suffer through the process of getting the, the lights in and the wires connected and the battery up, but the part that interests her is making the skull, not…figuring out where it would be, make more sense to put the battery or whatever. [parent pre interview]

> She's really now seeing this as a furtherance to art I think, as opposed to a, "Let's have something else so I can tinker and see how it works". It's like, "Okay. Now I have this vision and I see how this component fits into it. Let's get some more of those and see if we can create this experience." [parent midpoint interview]

Claim 1. Allison's design plans are not strict guides for her robot building activities

Evidence gathered from design journals, workshop video, and photographs suggests that Allison developed design plans for her robot at the start of each session that were generally, but not strictly adhered to during her robot building.

Session 1. Allison's initial robot sketch shows a robot with a round body, two LED eyes, and three appendages (two on the side and one on the top) each controlled by a servo. All of the components are plugged in to a hummingbird. There is a star on the top appendage [sketch 10/9]. A number of these elements were implemented during the first robot design session, including the round body, 2 LED eyes, and a top and side appendage with servos plugged into a hummingbird [workshop video and photographs 10/9]. The second appendage is added during the next design session. Allison also added a triangular stand to her robot during this session. It is not clear whether the stand was previewed on this sketch – there is an unlabeled rectangle on the sketch of Lily's back. It is possible that this rectangle is meant to represent the robot's support stand.

Session 2. Allison's second robot sketch featured a round robot with three appendages (two wings and a feather), two LED's (labeled 'orbs'), two vibration motors, and a hummingbird [sketch 10/16]. During this session Allison adds the additional arm and the vibration motors.

She also adds a speaker, which was not previewed in her sketch [workshop video and photographs 10/16].

Session 3. Allison's third robot sketch showed her robot with the addition of motors and wheels (sitting in what appears to be a box) [sketch 10/23]. Allison does add a box to her robot during this session, but for a variety of reasons never adds the motors and wheels. She also adds two LED lights to the box and moves her vibration motors [workshop video and photographs 10/23]. The lights, and the new vibration motor location are not previewed in this sketch.

Claim 2. Allison generates a lot of ideas, but often relies on others to evaluate the technical feasibility of those ideas

Evidence gathered from workshop video, design journals, and interviews suggest that Allison generates a number of design ideas for her robot. However, she seems to have particular difficulty in evaluating her own design ideas. Workshop instructors, or in once case a member of the curriculum team, often need to help her evaluate her design ideas. Allison's mother identified this as an area of difficulty for Allison, commenting that her daughter "doesn't have any particular sense… of testing or of iteration, of analyzing, stepping back to analyze how to get something to work and to put it together in steps to get there" [parent pre interview]. In some instances, Allison also required assistance in implementing her design ideas.

Session 1. Allison generates a host of ideas about building her new robot, many of which she implements independently. For example, she decides her robot is going to be a bird, and builds it to match her aesthetic criteria.

As Allison herself states, her most difficult problem during this session was making her robot stand up [reflection 10/9], a goal encouraged by the workshop instructors. Her initial idea is to place a long piece of foam board underneath and glue the robot on top of it. After devising this solution Allison exclaims, “I solved my support problem, yay!” but never actually tests her solution by gluing the support to the robot and seeing if it stands up. This idea is unlikely to work, but Allison does not realize this until Carol points it out and helps her devise a new plan (building a triangle support structure) [workshop video RD_c2_10_9_08]. This is an example of Allison generating an idea but not fully evaluating it, and it is not until Carol evaluates the idea for her and then suggests a new solution that the problem is solved.

In this session, we also see an instance of Allison developing an idea but requiring support to implement that idea. The idea is to have the top feather spin so that each end of the feather can represent a different emotion, but Allison cannot figure out how to attach the feather in a way that will allow this. Frustrated, she tells Meg that she will need to start over. Meg then suggests a way for Allison to attach the feather so that it can still achieve her goal [workshop video RD_c2_10_9_08].

Session 2. During this session, Allison receives encouragement to evaluate her own ideas from Meg. This happens most clearly after Allison has added the vibration motors to the robot, and Meg encourages Allison to test them to sure they work the way she intended [workshop video RD_a1_10_16_08]. The resulting test reveals two problems for Allison – the vibration motors do not vibrate the robot, and the wing collides with the robot’s stand. Meg helps Allison troubleshoot the placement of the wing by suggesting that she re-glue it in a new location. Allison tries to troubleshoot the vibration motors herself by moving them around (she continues to move the location of these motors in the next session as well). While she is satisfied with the ‘angry’ sound they make, she is never able to make the motors vibrate the entire robot. It is likely that the robot never vibrates because the motors are too small (compared to the size and weight of the robot)[17], but Allison never makes this observation.

During the midpoint interview, Allison expresses an idea about programming her robot to dance to music – she will make the robot recognize and respond to different notes played on her saxophone. However, during the final interview she does evaluate this idea and realizes that it is not realistic because her robot does not have a sound sensor, and even if it did it would be difficult for the robot to recognize individual notes [midpoint interview, final interview].

Session 3. Allison's sketch reveals that she planned to add four motors and wheels to her robot during this session [sketch 10/23]. However, a curriculum team member lets Allison know that this idea would not work by pointing points out that there are only two motor ports on the hummingbird. Allison then re-thinks her idea and develops an alternative solution (making a box with two wheels to move the robot). However, she is not able to implement this idea without help – Carol winds up building the box for Allison's robot [workshop video RD_b1_10-23-08, RD_b2_10-23-08]. Allison never actually adds the wheels to her robot, but it is not clear if she makes this choice because the motors are not available at the time she is building, or if she gave up on the idea.

Claim 3. Allison's design choices are primarily motivated by expressive goals

Evidence collected from workshop video, design journals and interviews suggest that, at least for the first two design sessions, the majority of Allison's design choices were motivated by expressive goals. This tendency is less evident in the third design session.

[17] This interpretation was suggested by members of the Robot Diaries curriculum team.

Session 1. Many of Allison's design choices during this session were motivated by a desire to build an expressive robot within a certain aesthetic vision. Even in her initial robot sketches, Allison was thinking about specific emotions her robot could express and how she could engage and combine the robot's expressive elements (eyes and the top feather) to produce both positive and negative emotions [sketch 10/9; workshop video]. Allison also describes her desire to make the robot look 'cute' [reflection 10/9; midpoint and final interviews] as guiding her overall robot design. The robot's triangular stand serves a functional (as opposed to expressive) purpose – it helps the robot stand up. However, it is worth noting that the workshop instructors encouraged her to add the stand [workshop video]. It is hard to say whether Allison would have added this element if the instructors had not encouraged her to do so.

Session 2. Allison adds a second wing, vibration motors, and a speaker during this session. The vibration motors are meant to denote anger in the robot, either by making it shake or by making an 'angry' sound as they hit the cardboard [workshop video; midpoint interview; reflection 10/16]. The speaker is also used as an expressive element. We can see this most clearly in the way the speaker is used in programming. In the 'hysterical' program, for example, the chirping sound coming out of the speaker is supposed to denote the robot crying [workshop video RD_a2_10_16_08]. Allison also comments that "it just sounds really nice when [the robot] goes tweek. She just looks all excited all the time" [final interview], suggesting that the speaker contributes to the robot's expression of excitement.

Allison's motivation for adding the robot's second wing is less clear. Aside from the obvious aesthetic appeal of adding a second wing (birds have two wings), Allison explains that the second wing will help the robot balance [workshop video RD_a1_10_16_08]. However, in the midpoint interview, Allison says that the second wing helps with 'expression and realisticness' [midpoint interview]. Likely, the addition of this second wing is motivated by both expressive goals and the desire to balance the robot. Although as Allison points out, the need for balance is an important part of building crafts [midpoint interview], making this motivation consistent with her point of view as an artist.

In the midpoint interview (which followed this session), Allison explained that she chose not to add certain elements to her robot because they did not fit with her aesthetic ideas. One example of this is eyebrows, which she chose not to add because they would have made her robot look more 'American' [midpoint interview].

Some of Allison's choices while programming her robot are also motivated by a desire to enhance emotional expression. When asked how she produces program for her robot, Allison says that she thinks about how a bird (in particular the instructor's bird) or a person would express certain emotions, and uses those images to program her robot [midpoint interview].

Session 3. Towards the end of this session Allison comments, "I didn't really add anything new. I thought about the, I just improved the structure" [workshop video RD_b2_10-23-08]. An examination of the workshop video reveals some truth to this statement. Allison spent the majority of the session trying to add wheels, and a box to support them, to the bottom of her robot. Allison's motivation for wanting to add the wheels is not entirely clear. She comments in her midpoint interview that it would be "kind of cool if it could like walk or something. Like roll on wheels" [midpoint interview], but never specifies any structural or expressive purpose for the wheels. In the end Allison adds only the box. The box does help to make the robot more balanced [final interview], but Allison's original intention in adding the box was as a support for the wheels.

Allison's other activities during this session are re-organizing the robot's wires and adding lights to the robot's bottom box [workshop video]. However, Allison does not explain her exact motivation for either of these activities.

In the final interview, Allison comments on some of the other technology that was introduced during the workshop. She describes being very excited about the potential of the sensors:

> well first I wanted to make it be able to just sort of turn, make the lights turn on and off but then I was sort of getting interested in what it could look it was doing and when the sensor came I was like oh that sounds interesting. Merry Christmas. Happy Hanukkah. Those are a few things it could say. Happy birthday Allison. Trick or Treat. [final interview]

This is another example of Allison thinking ahead to the expressive goal that could be fulfilled by the technology.

Claim 4. Allison has developed creative solutions to meet her expressive goals

Allison's plan for her robot's top feather represents a novel solution to meeting an expressive goal. Her original plan (which she only partially implements) is for the feather to spin around, displaying either the side with a star for 'happy' or the side without a star for 'sad' [sketch 10/9]. In this plan, the star becomes an abstract symbol of emotion – its presence or absence alerts the viewer to the robot's state of mind.

Claim 5. Allison sees her robot as a representation

At times, Allison's robot seems to represent a fictional character (Lily) that Allison has created. At other times the robot appears to represent Allison herself.

The evidence for viewing Lily as a character is supported by Allison's actions and comments about the robot. For example, Allison makes Lily a costume so she can dress up for Halloween (see Figure 15). Allison also has clear ideas about Lily's look and personality. In explaining her design choices, Allison repeatedly states that Lily has a 'minimalist' and 'Japanese' look [midpoint interview, final interview], and an expressive personality.

The idea of Lily as an extension of Allison herself comes out of Allison's comments during interviews. In the midpoint interview, Allison explains how Lily can express some of the emotions that Allison herself cannot:

> An interesting theory is that if there was a world where everyone showed what they thought and a person from that world came to earth, all of the earth people wouldn't like that person because they showed everything that they thought…if we have a bad thought we don't ever say it. We keep it in. Some people keep it – I know I try to keep it in, but it would look unusual so I'm making my robot kind of like that. [midpoint interview]

More literally, Allison uses the robot to express emotions for her on the messenger site, such as the 'sick' program she posts along with the message, "seriously, I'm not feeling so good" [messenger posting 10/14].

Finally, like Allison, Lily has a younger sibling who sometimes gets in her way:

> I was going to make a dance sequence so Lily's was trying to dance and there was music and the little bird would come in and go tweet and she'd go urr. Tweet. *Because siblings, younger siblings can be kind of annoying sometimes.* [final interview]

Claim 6. Allison is hot and cold in her confidence with the technical elements of robot building

Allison began the workshop with technology confidence ratings that were slightly lower than average for this group for technology (her ratings were higher for art)[18]. In their pre-interviews, Allison and her mother both described a recent incident wherein Allison accidentally erased a recording from the family's digital video camera by pressing the wrong button. Allison's mother explained that her daughter has always been cautious in her approach towards new technology, and believed this particular incident led her to "much more of a sense than she ever did that if you hit the wrong button it really can blow up" [parent pre interview]. At the post interview, Allison's mother comments that while the workshop has led to many positive outcomes, she did not see a major change in Allison's confidence. As she explains in her final interview, "I was impressed that when things fall off she puts them right back on and she re-hooks them, but she didn't pick up as much of the 'okay it's not working, how can I step myself through the process of fixing it' as I'd hoped that she might" [parent final interview].

By the end of the workshop Allison's confidence ratings for computers and robots have increased, but they are still below the average group ratings[19]. Allison's comments during the workshop and in interviews reveal a mixture of positive and negative feelings towards her own abilities in this area. During the first workshop session, her confidence reaches a low point when she tells Meg that she will need to start over because her idea did not work. However, as revealed by her mother's message to the researcher, Allison was confident in her ability to fix

[18] Allison's pre workshop confidence ratings were as follows (with group averages in parentheses): everyday technology = 4 (4.43), computers = 3 (4.02), robots = 3 (3.52), art = 5 (4.53).
[19] Allison's post workshop confidence ratings were (with groups averages in parentheses): everyday technology = 4 (4.33), computers = 3.67 (4.22), robots = 4 (4.52), art = 5 (4.33).

her broken robot at home. During the second robot design workshop, Allison states "when I thought about building robots, I thought it'd be much harder. It's actually pretty easy, if you know what to do" [workshop video RD_a1_10_16_08]. This statement is supported by her comment in the midpoint interview, "I'm pretty sure about building [robots] now, like simple ones. I guess complicated ones. I guess I – I don't know a lot of complicated stuff, but if bet if I learned it I could do it easily." However in this interview she still expresses doubt that she could fix elements on the robot that were not working, such as the speaker:

> Well I'm not that good in that sort of sense. I've been used to fixing crafts all the time cause I've been doing crafts since I was two or three. But I'm not that much of a computer person. So usually I ask my mom and she usually figures it out. But I think it's gonna be easier now that I know more about how it works [midpoint interview]

Interestingly, Allison does express confidence in her ability to design and 'begin to build' [midpoint interview].

3.6 CONCLUSION

This chapter presented in-depth accounts of two Robot Diaries participants, each of whom experienced the workshop in a different way. Dakota approached the workshop primarily as an engineer, although she also engaged the workshop's artistic goals. Allison approached the workshop primarily as an artist. These two participants represent different ways of engaging with the curricular content of Robot Diaries. However, while their approaches may have differed each participant had an experience that helped her move towards fluency. This becomes most apparent when we consider their participation in light of the three habits of mind.

3.6.1 Engaging in a technology design process

Dakota was an effective technology designer. She was planful, careful, and able to evaluate her own design ideas in light of technological constraints. She was also able to keep both technical and expressive goals in mind as she designed and built her robot. Dakota may have possessed some of these design skills prior to the workshop (this seems likely based upon her prior experience and interests). However, participating in Robot Diaries provided her with an opportunity to practice these skills in the context of personalizing and adapting robotic technology.

Allison developed a set of expressive goals for her robot. With help, she was able to complete the technology design process and produced a robot capable of meeting those goals. Allison did have difficulty evaluating and troubleshooting her technical ideas. The workshop provided her with the opportunity to see these skills modeled by others, and to practice them herself.

3.6.2 Beliefs about technology

Dakota demonstrated her flexible beliefs about technology both by using her robot creatively (e.g, during the workshop she developed creative solutions for meeting both technical and expressive goals), and by using her robot to express her personal interests in music and current events.

Allison also demonstrated flexible beliefs about technology. She developed creative solutions for meeting expressive goals, and used her robot as a representation (of herself and the character Lily). Allison's prior activities suggest that she is a creative child, but Robot Diaries provided her with the opportunity to practice her creativity in a technological realm.

3.6.3 Confidence

As Dakota herself indicates, she began the workshop with a fairly high level of confidence in her own abilities. The workshop may have served to increase her confidence slightly. Allison began the workshop with less confidence in her abilities, and made some (but limited) progress in this area.

4.0 PRE-POST ASSESSMENTS

Chapter 3 described a qualitative approach to examining technological fluency in the Robot Diaries learning environment. The current chapter presents a set of measurement tools for the assessment of technological fluency. These tools, developed with guidance from relevant literatures (as described below), were used to assess Robot Diaries participants prior to the start of the workshop, and again at the conclusion.

Participants engaged in pre/post workshop interviews and tasks designed to measure the impact of workshop participation on three key areas of fluency development: (1) confidence and interest with respect to technology, (2) recognition of creative and expressive uses of technology, and (3) technological content knowledge. Confidence and interest were measured via written surveys adapted from the existing literature on technological fluency (see Mercier, Barron, & O'Connor, 2006). Recognition of creative and expressive uses of technology was measured using concepts adapted from the creativity literature. This literature has developed numerous methods for measuring an individual's ability to generate novel and appropriate ideas about the design and use of objects (see, for example, Finke, Ward, & Smith, 1992 and Wilson, Guilford, & Christensen, 1953), some of which were adapted as part of the current assessment. The assessment of technological content knowledge focused primarily on procedural, declarative and qualitative knowledge (i.e., contextually-relevant technology or systems knowledge expressed in qualitative, as opposed to scientific and quantitative, terms; McCormick, 2004)[20]. Such content knowledge is believed to underlie an individual's ability to engage in a technology design process (Bernstein, 2007), in addition to being a legitimate outcome in its own right.

Results are presented according to the three topic areas outlined above, and then summarized. The final section of this chapter offers suggestions for improving the measures described here.

4.1 CONFIDENCE AND INTEREST

Confidence and interest with respect to technology were measured via written surveys administered before and after the workshop. The survey instruments were adapted from those used by Mercier, Barron, and O'Connor (2006).

4.1.1 Confidence

A written survey was used to measure participants' confidence with respect to three themes relevant to the Arts and Bots workshop – robots, computers, and art. Confidence was also assessed with respect to everyday technology as a measure of transfer (i.e., to determine if participants' experiences in the workshop were influencing their interactions with everyday technologies outside of the workshop). The confidence survey consisted of 12 items. The same

[20] Some of the technological content knowledge assessments were also used with an earlier version of the Robot Diaries curriculum (see Hamner, Lauwers, Bernstein, Nourbakhsh, & DiSalvo, 2008).

basic question structure was used for each theme (see Mercier, Barron, & O'Connor, 2006). Questions read as follows:

- I feel confident about my ability to [use computers/make robots/do art/use everyday technology (like cell phones and iPods)]
- I am the kind of person who [works well with computers/is good at making robots/is good at making art/works well with everyday technology]
- I am good [with computers/at making robots/at art/at using everyday technology]

Responses were captured on a 5-point Likert scale with options ranging from 'strongly disagree' to 'strongly agree.' Participant's responses were averaged across the three questions for each subscale (computers, robots, art, everyday technology). Figure 16 shows the average pre/post ratings for participants on each of the four subscales[21].

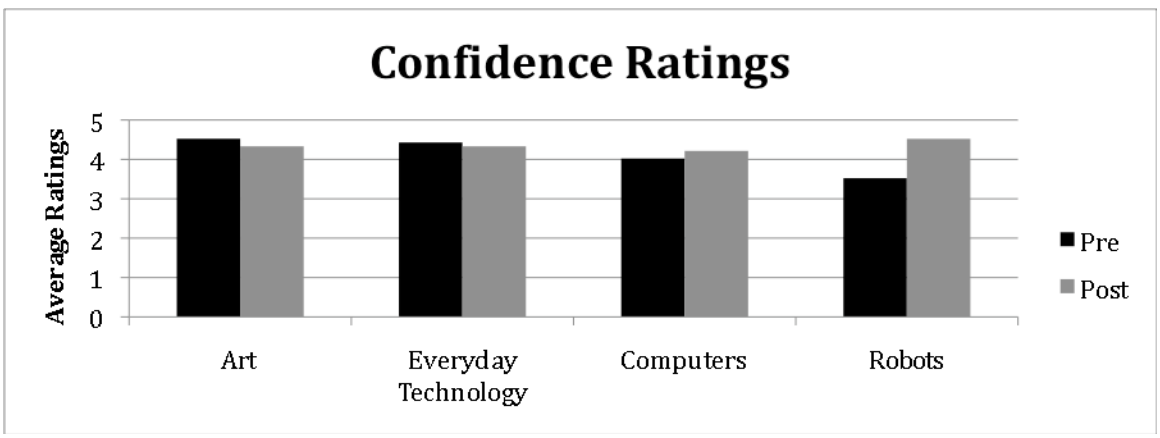

Figure 16. Participants' average confidence ratings

Participants' computer confidence ratings are within the range reported by Mercier et al. (2006) [22]: M = 4.41 (SE = 0.25) for participants who identified themselves as 'computer-type' people,

[21] In cases where an item was left blank on either the pre or post survey, the participant's response to that question on the matching survey was not counted. This was the case for one question on Noel's pre confidence survey, one question on Noel's post interest survey, and two questions on Allison's post interest survey.

M = 4.40 (SE = 0.30) for participants who said they may be 'computer-type' people, and M = 3.62 (SE = 0.12) for participants who said they were not 'computer-type' people. The mean interest rating for the computer subscale in the current study, which used the same questions as Mercier et al.'s computer confidence measure, was 4.02 (SE = 0.33) at pre-interview and 4.22 (SE = 0.31) at post interview.

Figure 17 shows the change in average subscale ratings from pre to post survey for each participant. Absence of a bar for a particular subscale means there was no pre-post change for that subscale.

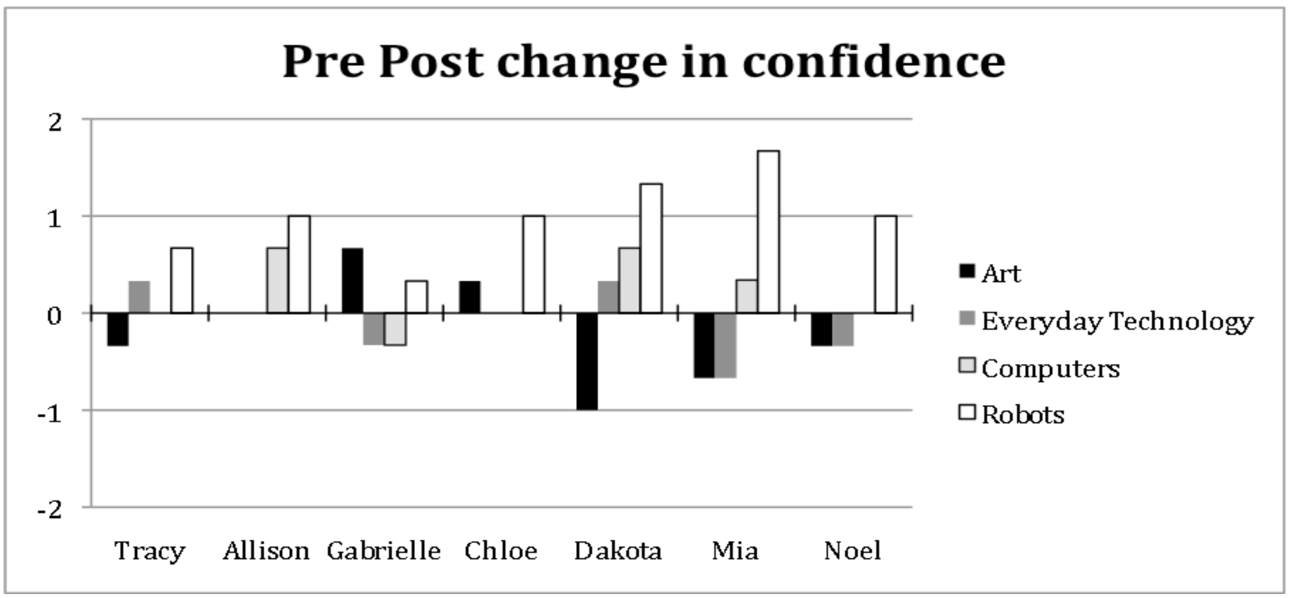

Figure 17. Changes in confidence self-ratings for individual participants

Results suggest that all seven participants were more confident in their ability to engage with robots after the workshop. No global patterns of change are apparent in participants' levels of confidence to engage with art, computers, or everyday technology.

[22] The Mercier et al. (2006) sample included 121 middle school students. Their confidence and engagement measures only asked about computers. Responses to confidence and engagement measures were categorized according to participants' answer to the question, 'Are you a computer-type person?'

4.1.2 Interest

Participants' interest was also measured with respect to four themes – art, everyday technology, computers, and robots. The interest survey consisted of 24 items. The same basic question structure was used for each theme (see Mercier, Barron, & O'Connor, 2006). Questions read as follows:

- I would like to learn more about [computers/art/robots/everyday technology//how everyday technology works]
- It is important to me that I am knowledgeable about [computers/art/robots/everyday technology]
- Learning about what [computers can do/art/robots can do/everyday technology can do/how everyday technology works] is fun
- I like the idea of taking [computer/art/robotics] classes/classes about [everyday technology]
- [Computers/Art/Robots/Everyday technology] is/are interesting to me
- I enjoy building or making things
- I would like to learn more about technology design

Responses were captured on a 5-point Likert scale with options ranging from 'strongly disagree' to 'strongly agree.' Participant's responses were averaged across the questions for each subscale (computers, robots, art, everyday technology). The questions on building and technology design were treated separately. Figure 18 shows the average pre/post ratings for participants on each of the four subscales.

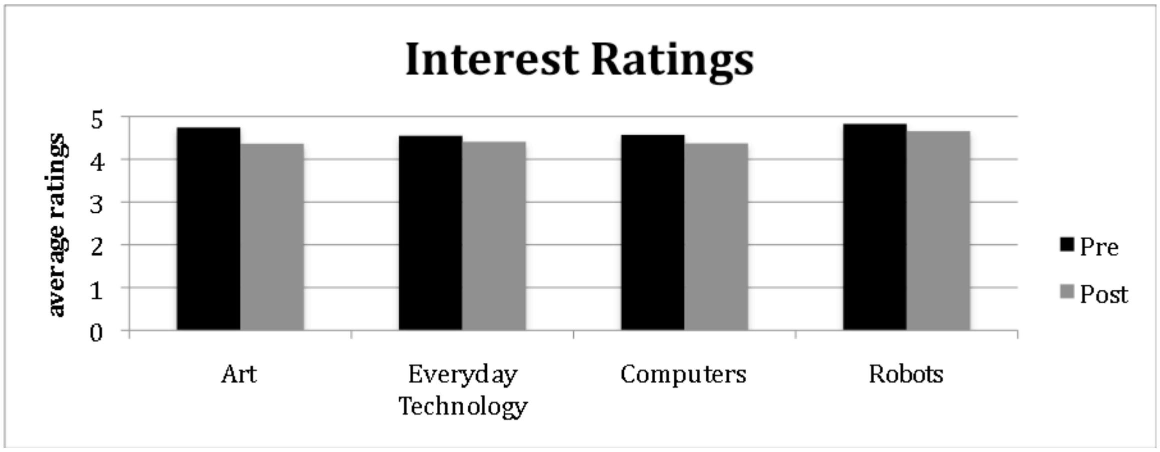

Figure 18. Participants' average interest ratings

When compared with the Mercier et al. (2006) sample, participants in the current study began the workshop with a higher than average interest in computers. Mercier et al. (2006) report the following scores on their computer engagement measure: M = 4.13 (SE = 0.23) for participants who self-identify as a 'computer-type' person, M = 4.17 (SE = 0.27) for participants who say they may be a 'comptuer-type' person, M = 3.62 (SE = 0.12) for participants who do not identify themselves as 'comptuer-type people'. The mean interest rating for the computer subscale in the current study, which used the same questions as Mercier et al.'s computer engagement measure, was 4.57 (SE = 0.22) at pre-survey and 4.37 (SE = 0.24) at post survey.

Figure 19 shows the change in average subscale ratings from pre to post survey for each participant.

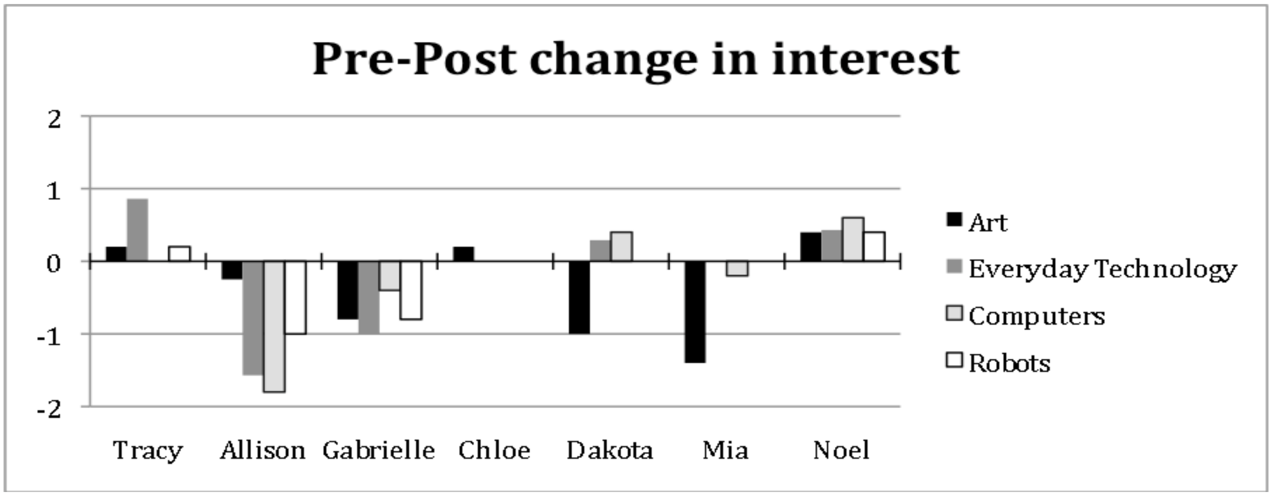

Figure 19. Changes in confidence self-ratings for individual participants

Results do not suggest any global patterns of change in participants' average levels of interest in computers, everyday technology, art, or robots.

Participants' responses to the question 'I enjoy building or making things' remained stable from pre to post survey – scores decreased for 1 participant and remained the same for 4; two participants failed to answer the question on either pre or post surveys. Responses to the question 'I would like to learn more about technology design' generally declined from pre to post survey – scores decreased for 4 participants, increased for 1 participant, remained the same for 2 participants.

4.2 CREATIVITY AND DESIGN

The two tasks described in this section were designed to capture different aspects of participants' ability to be creative with technology, thereby informing understanding of their development with respect to the ‘seeing technology as a tool and creative medium’ habit of mind.

The first task, Creative Uses, assesses participants’ ability to think about atypical uses of common consumer technologies (e.g., a cell phone and a digital camera) and technological capabilities (e.g., lights, sensing, and motion) in two different problem situations. This task is a measure of divergent thinking with respect to technology (Cropley, 2006). The second task, hereby called the Design Task, asks participants to design and model a novel technology that will help solve a community problem. The design task measures participants’ ability to both generate novel ideas about how to use technology *and* make judgments and choices about which of those ideas to implement. This latter task represents a measure of both divergent and convergent thinking (Cropley), and allows for a more controlled exploration of participants’ developing design capabilities.

4.2.1 Creative Uses Task

4.2.1.1 Task Description.

Participants were asked to describe the different ways they could use specific technologies (a consumer technology or a robot they build themselves) in two different scenarios: (1) an invasion of their privacy, or (2) the occurrence of negative behavior in a loved one. The scenarios read as follows, with pre/post interview alterations indicated in brackets:

> You have noticed that someone has been [coming in to your bedroom/going through your closet] when you are not there, and is looking through your stuff. How could you use technology to help protect your privacy?

Someone you know and care about has [started smoking/started eating in a very unhealthy way]. How could you use technology to help them [quit/be healthier]?

Each scenario was presented twice. During the first presentation, participants were asked how they could use a consumer technology to help alleviate the problem (a cell phone in the privacy scenario, a digital camera in the negative behavior scenario). During the second presentation, participants were asked how they would build a robot to help alleviate the problem, assuming the robot had three capabilities – it could move, sense the environment, and light up. Participants were then asked a series of follow-up questions:

- So how would that work? Can you tell me more about how it would work?
- Now, if you were going to make that, what steps would you take?
- What would be the most challenging part about building this?
- Do you think you could do/build something like this?

4.2.1.2 Task Coding.

Responses to the first presentation of each scenario, when participants were asked how they would use consumer technologies, were coded for both the number of unique ideas generated and the novelty of each idea. (Each of these metrics has been used to assess participant responses to creativity tasks - see Diakidoy & Constantinou, 2000-2001, and Wilson, Guilford, & Christensen, 1953, for examples from the creativity literature; see also Shah & Vargas-Hernandez, 2003, for a discussion of these metrics in the context of engineering design). With respect to novelty, each idea was categorized as describing a 'typical' or 'atypical' use of that technology. Typical uses of a cell phone include: calling people, taking pictures, sending messages, setting an alarm to go off at a specified time, and recording video/audio. All other uses were coded as 'atypical'. Typical uses of a digital camera include taking pictures and recording video. Very few participants suggested atypical uses for the camera. Inter-rater reliability was determined by having two raters code 20% of the data for both number of ideas and the typicality of each idea. Reliability was above 85%.

Responses to the second presentation of each scenario, when participants were asked how they would build a robot, were coded for the number of ideas about how the robot could utilize each of its capabilities (i.e., how many ways could the robot use sensing, motion, lights, or other imagined capabilities to address the problem). Each idea was additionally categorized as being 'original' or 'frequent' in this particular situation. An idea was coded as original if no more than 2 participants had suggested it during the pre or post interviews. Inter-rater reliability was calculated for the first scenario (privacy) by having two raters code 20% of the data for number of ideas. Reliability was 100%. The two coders then made designations of original or frequent ideas by working together to discuss and categorize each idea. A single coder (the author) then applied the same coding principles to the second scenario (negative behavior).

4.2.1.3 Results.

Participants had the opportunity to develop solution ideas for 4 scenarios in total: (1) invasion of privacy + cell phone, (2) invasion of privacy + robot, (3) negative behavior + digital camera, (4) negative behavior + robot. Participants' responses to the consumer technology (cell phone/digital camera) scenarios will be described first, followed by responses to the robot scenarios.

Figure 20 presents the number and typicality of responses to the cell phone/privacy scenario during pre and post interviews.

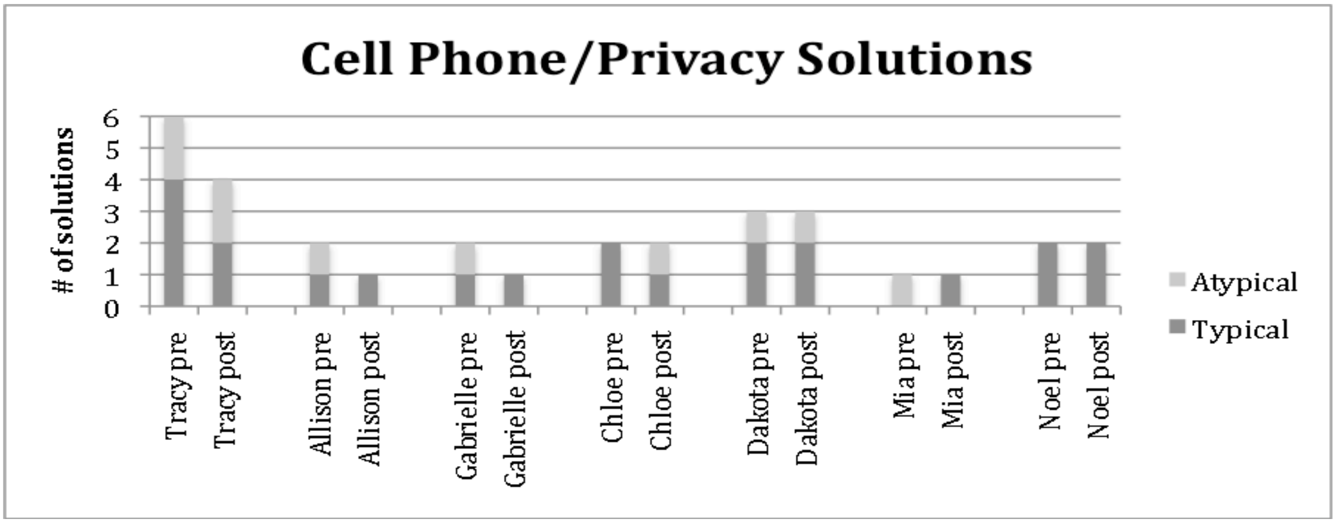

Figure 20. Number of solutions for the cell phone and privacy scenarios

Three of the participants – Tracy, Allison, and Gabrielle – suggested fewer solutions to this scenario in the post interview than they did in the pre interview. The other four participants displayed no change in the number of solutions suggested at each time point. However, while many participants had the same number of solutions at pre and post, many of the actual solutions were unique (i.e., not repeated from pre to post)[23]. Only one participant presented an atypical response for the first time on the post-test.

The most frequent solutions at pre test included: using the phone as a motion detector (4 participants), using the phone to take pictures of the intruder (3 participants), recording audio (2 participants), and playing a recording of you talking (2 participants). The most frequent solutions at post test included: taking pictures of the intruder (4 participants), and placing the phone in your closet and then calling it (2 participants). Only one participant suggested using the phone as an alarm or motion detector at post test.

[23] The percentage of post interview solutions also present at pre interview (for each participant, respectively): 25%, 100%, 100%, 0%, 100%, 0%, 50%.

Figure 21 presents the number of responses to the digital camera/bad behavior scenario. Very few responses were categorized as using the digital camera in an atypical way, so responses have been collapsed across typicality.[24]

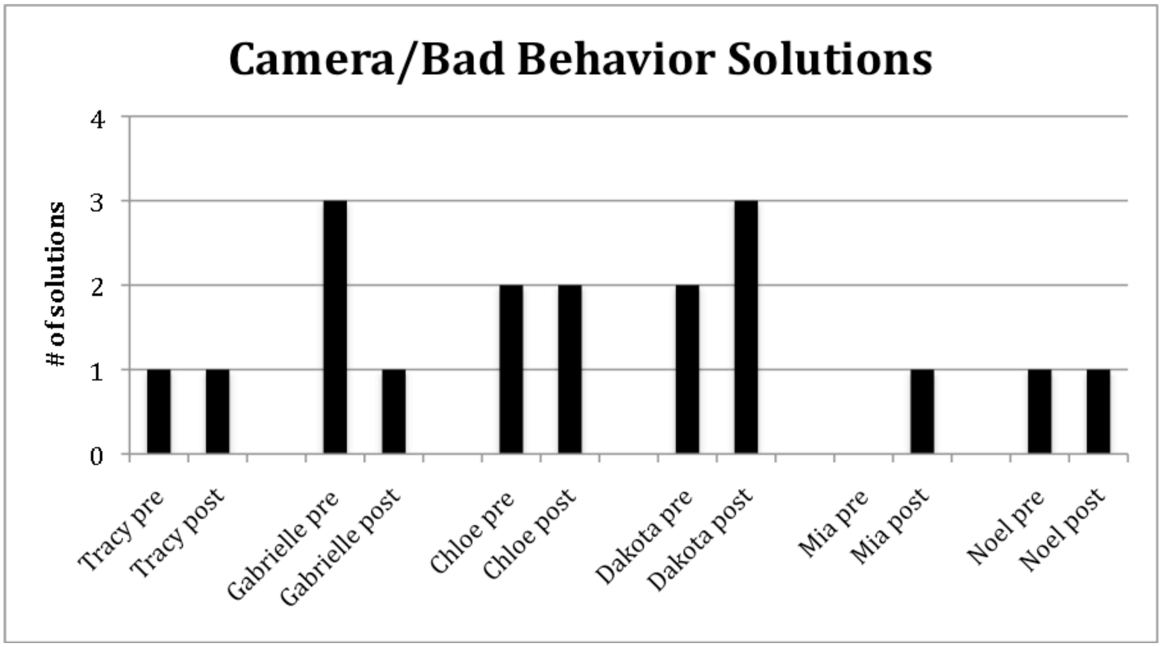

Figure 21. Number of solutions for the camera and bad behavior scenarios

Dakota and Mia suggested more solutions at the post interview than the pre interview, while Gabrielle suggested fewer solutions at post. The three remaining participants suggested the same number of solutions at both interviews[25]. The most frequent solutions at pre test included: taking pictures of the person smoking/engaging in the negative behavior (5 participants), and taking pictures of their lungs (2 participants). The most frequent solutions at post test included:

[24] Due to time constraints during the pre-interview, Allison was not asked about the bad behavior scenarios, so her data has been removed from this analysis.
[25] The percentage of post interview solutions also present at pre interview (for each participant, respectively): 100%, 100%, 0%, 0%, 0%, 100%.

taking pictures of people with health problems related to eating poorly (3 participants), and taking pictures of what the person eats (2 participants).

Solutions to the privacy/robot scenario were coded for pre-post comparison by counting the number of sensing, movement, lighting, and other behaviors the robot would display. The robots described by participants included most (or sometimes all) of these abilities. For example, Chloe's pre and post test robots both sensed movement and responded by moving around under another object such as a bucket (so that the object appeared to be moving on its own – a tactic designed to scare the intruder) while flashing its lights. Dakota's pre test robot rotated around on her desk and shot video from a moving camera. When it sensed movement either on the videotape or via an additional sensing mechanism (sonar), it would trigger indicator lights and/or bright lights to induce the intruder to leave. Her post test robot used a distance sensor to sense movement at the closet door and lit up to scare away intruders. The robot could then follow the intruder using a variety of sensing mechanisms (such as light, heat, distance, color, or motion).

Figure 22 presents the total number of robot behavior ideas developed in response to the privacy/robot scenario.

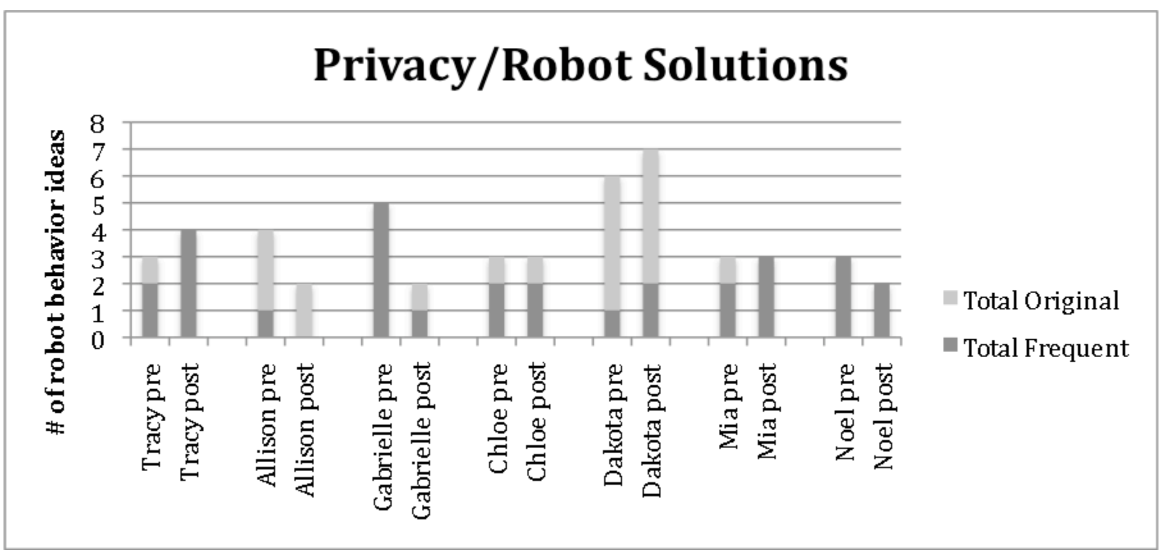

Figure 22. Number of behavior ideas for the privacy and robot scenarios

As the figure indicates, two participants (Tracy and Dakota) displayed a pre to post increase in the number of ideas for the robot's behavior, while three participants (Allison, Gabrielle, and Noel) displayed a decrease and two participants (Chloe and Mia) remained stable in the number of robot behavior ideas. There is no discernable pattern of movement from more frequent to more original ideas from pre to post (or vice versa).

Figure 23 indicates the breakdown of participants' ideas about the robot's sensing, motion, lighting, and other behaviors.

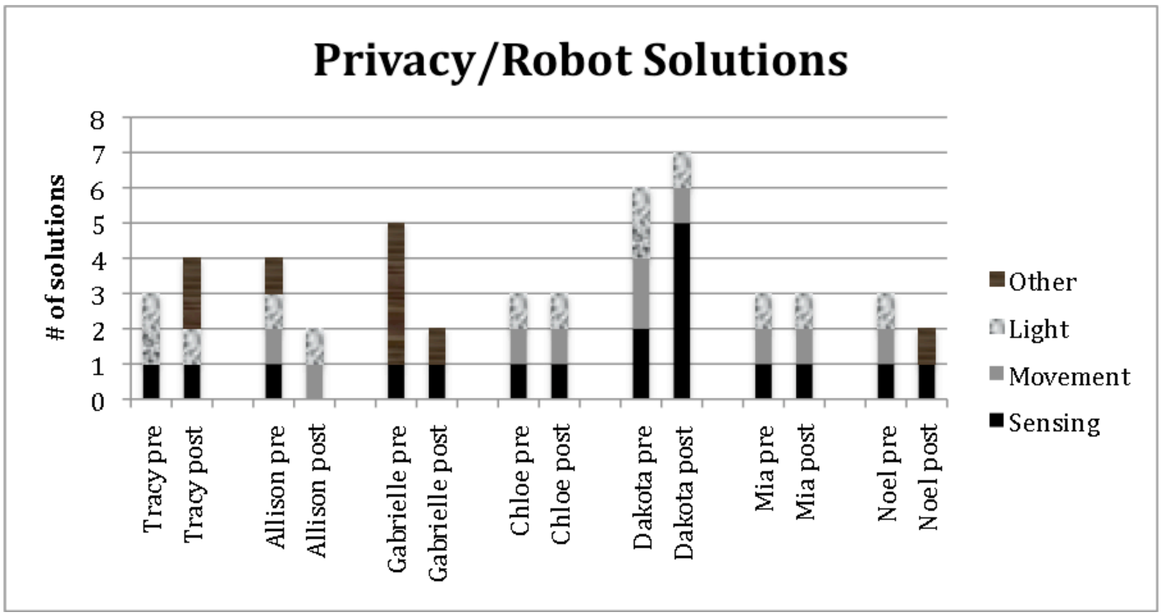

Figure 23. Number of solutions for the privacy and robot scenarios

The most frequent sensing behavior described at both pre and post test was sensing motion (5 participants specified that their robot would be able to sense motion at pre, 4 at post). While the majority of participants ascribed the same type of sensing behavior to their robot at pre and post, two participants, Gabrielle and Dakota, added light sensing to their robot's capabilities at post (light sensors were introduced during the workshop).

The majority of participants included movement in their descriptions of robot behavior, including the robot moving around to deter an intruder, the robot moving another object around to scare an intruder (Chloe) or a robot moving to find the room's original occupant when it sensed an intruder (Allison). Of the four participants who described movement in both their pre and post robots, all but one (Dakota) described the same type of movement at both time points.

The most common uses of lights in the privacy robots were simply lighting up in response to movement, or lighting up brightly enough to scare/blind an intruder. Two participants also described using lights to alert the owner that someone had invaded their privacy, and one suggested replacing the room's light fixture with a light from the robot. Of the five participants who described using lights in both their pre and post robots, all but one (Tracy) described the same use for the lights. Other robot behaviors included having the robot hold up a STOP sign, using speakers to enable the robot to communicate through sound (beeps or statements), and sending alerts via a pager or phone.

Solutions to the robot/bad behavior scenario were also coded for the number of sensing, movement, lighting, and other behavior the robot displayed. However, the pre/post alteration for the negative behavior scenario yielded largely independent solution spaces, making the coding of ideas for frequency/originality impractical across pre and post responses. While Figure 24 displays the number of pre and post behaviors for the robot, the aforementioned differences in solution space make a pre-post comparison for this scenario largely irrelevant.

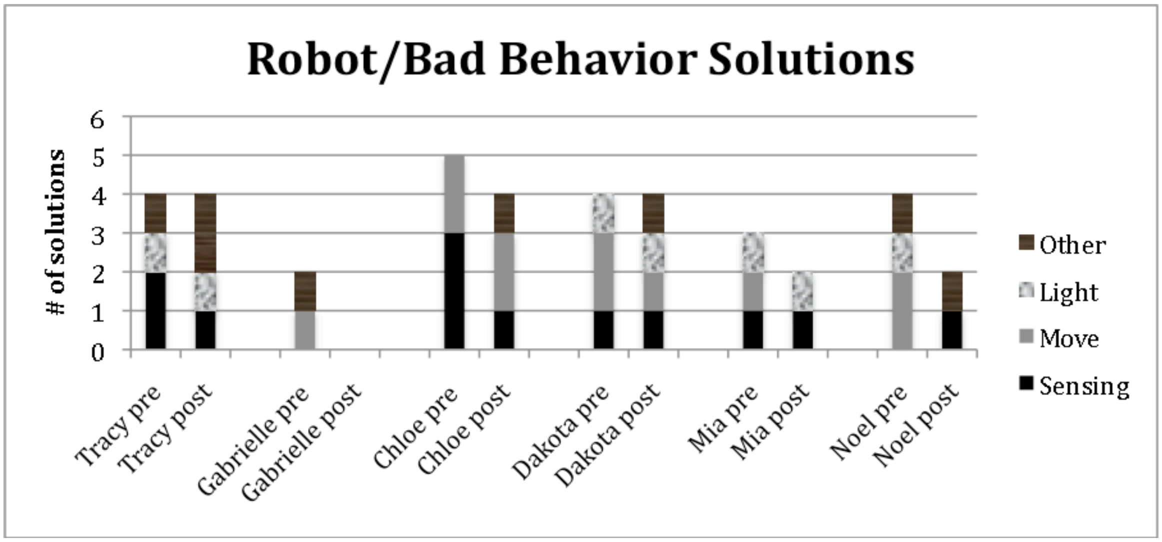

Figure 24. Number of solutions for the robot and bad behavior scenarios

4.2.2 Design Task

4.2.2.1 Task Description.

Participants were presented with two community problem scenarios – a noisy street (pre interview) and a smoky park (i.e., a park with a lot of smokers; post interview) – and asked to model a novel technology that could help alleviate these problems. Task instructions read as follows:

> Recently, you and your neighbors have noticed [statement of problem]. Knowing that you are interested in technology, the neighborhood association has hired you to develop a new technology that will help [restatement of problem]. They have asked you to build a prototype or model. A model can show what something will look like and how it will work once it is built. You will use these (craft) materials to make your model.

> In order to build your technology, they have given you the following parts: a sensor, a speaker, 2 lights, and 2 motors. What I'd like you to do now is imagine a technology that used those parts, and build a model of it using the craft materials. There is paper and a pencil here, so you can draw if you want to. While you're building, I'd like to know what you are thinking about, so try to talk out loud as you are building.

Participants were provided with paper, a pencil, and a variety of craft materials for model building (e.g., sheets of bendable foam, cardboard, popsicle sticks, masking tape, dowel rods, sticky tack, push pins, Styrofoam balls, markers, pipe cleaners, felt, scissors). They were allotted approximately 25 minutes to complete their designs. The researcher probed participants periodically during the building phase of the task. Once building was complete, each participant was asked to explain her design by answering the following questions:

- Can you tell me about what your model? How does it work?
- Do you think this will do a good job reducing the amount of noise on your street/smoke in the park? (please explain your answer)
- Let's talk about what would happen if someone wanted to take your model and built the technology that you have suggested/modeled.
    - How would they do it? What steps would they go through?
    - What materials or parts would they need?
    - Do you think it is likely that this machine would work/run [would it really do ____], or do you think it would not work? Why/not?
    - What would be hard/easy about it?
    - How could they test it (to make sure it was working)?
    - What challenges would they face in building this?

4.2.2.2 Task Coding[26].

The design task was meant to serve as a proxy measure both for participants' understanding of/ability to implement complex systems and their ideas about expressive uses of technology. As such, two coding schemes were developed for data analysis. The first analyzed the design solution as a human-robot system, exploring the proposed modes of interaction/communication, the creator's use of emotion in her robot design, and whether the robot was designed to be stand-alone or part of a larger technology system (Svensson & Ingerman, in press). The second coding scheme focused on the solution as an engineered system, examining both the number of entities present in the system and the different types of interactions between entities. Both coding schemes utilized transcripts of the design session.

Unlike the creativity task, which measured the number and novelty of participants' solution ideas, the design task was meant to capture information about participants' ability to both develop novel ideas about a technology *and* make realistic choices about its design (i.e., to engage in both divergent and convergent thinking; Cropley, 2006). Therefore, analysis for this task focuses only on the ideas instantiated in each participant's model. This includes follow-up explanations of how the model would work, but excludes both initial design ideas that were not acted upon[27], and redesign ideas described after participants completed their models.

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[26] Christiaans (2002) introduced seven criteria for judging designs, some of which were incorporated into the current coding scheme: creativity, technical quality, attractiveness, interest, expressiveness, integrating capacity (i.e., integration of 'form, function, and construction') and goodness of example. Expert explanations for judgments of creativity also suggested additional criteria, for example: form and function, impact on observer (i.e., triggering emotion), and integration.

[27] In the pre interview, two participants (Allison and Noel) changed their design ideas substantially after they began building their models. The remaining participants enacted only one main design idea during the model-building phase of the task, although some deliberated about their ideas before they began building. Some participants also presented a number of redesign suggestions during the post-building interview.

4.2.2.3 Description of Models.

Figures 25 and 26 show each of the models built during the pre and post design tasks. As is evident from the images, some participants utilized familiar forms (e.g., a sign, a traffic light, a face) while others developed a unique aesthetic for their proposed technology. Even in the pre interviews, some participants were thoughtful about the relationship between the robot's form and its function, as demonstrated by Tracy's traffic light meant to reduce noise and Dakota's bright lights that double as a signal to alert police to sustained noise levels.

The majority of the participants chose to design robots that could communicate directly with the public, and most of their systems used some form of negative reinforcement to extinguish unwanted behavior (e.g., anti-smoking or anti-noise messages spoken from a speaker). However systems differed in their intended audiences, with some systems targeting specific troublemakers (i.e., having the robot approach people who were smoking or making noise), some engaging the general public (i.e., by having the robot move around a park and remind everyone not to smoke), and some communicating with additional audiences such as the police. A few systems also employed escalating modes of communication to deter unwanted behavior, such as Mia's system that first flashed lights, then used a speaker, then sounded an alarm if the level of smoke in the park was still too high.

4.2.2.4 Results: Design solution as a human-robot system.

Two raters independently coded 20% of the design task transcripts for the number of interaction/communication modalities represented by each solution, the presence/absence of emotional engagement in each solution, and whether the proposed robot was stand-alone or part of a larger technology system; rate of agreement was 100%.

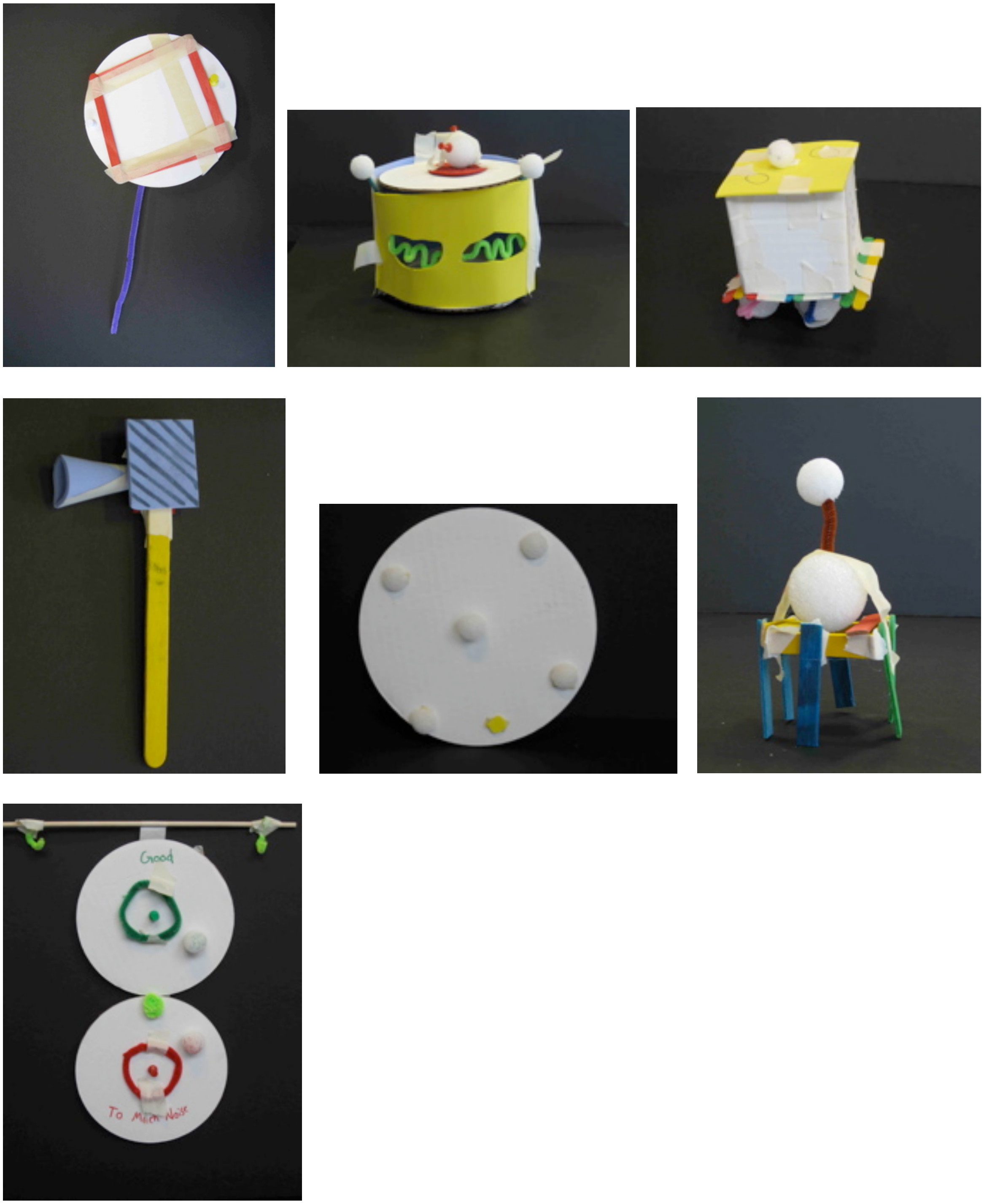


Figure 25. Design task solutions (pre interview).

1st row (left to right): Allison, Chloe, Dakota. 2nd row: Gabrielle, Mia, Noel. 3rd row: Tracy.

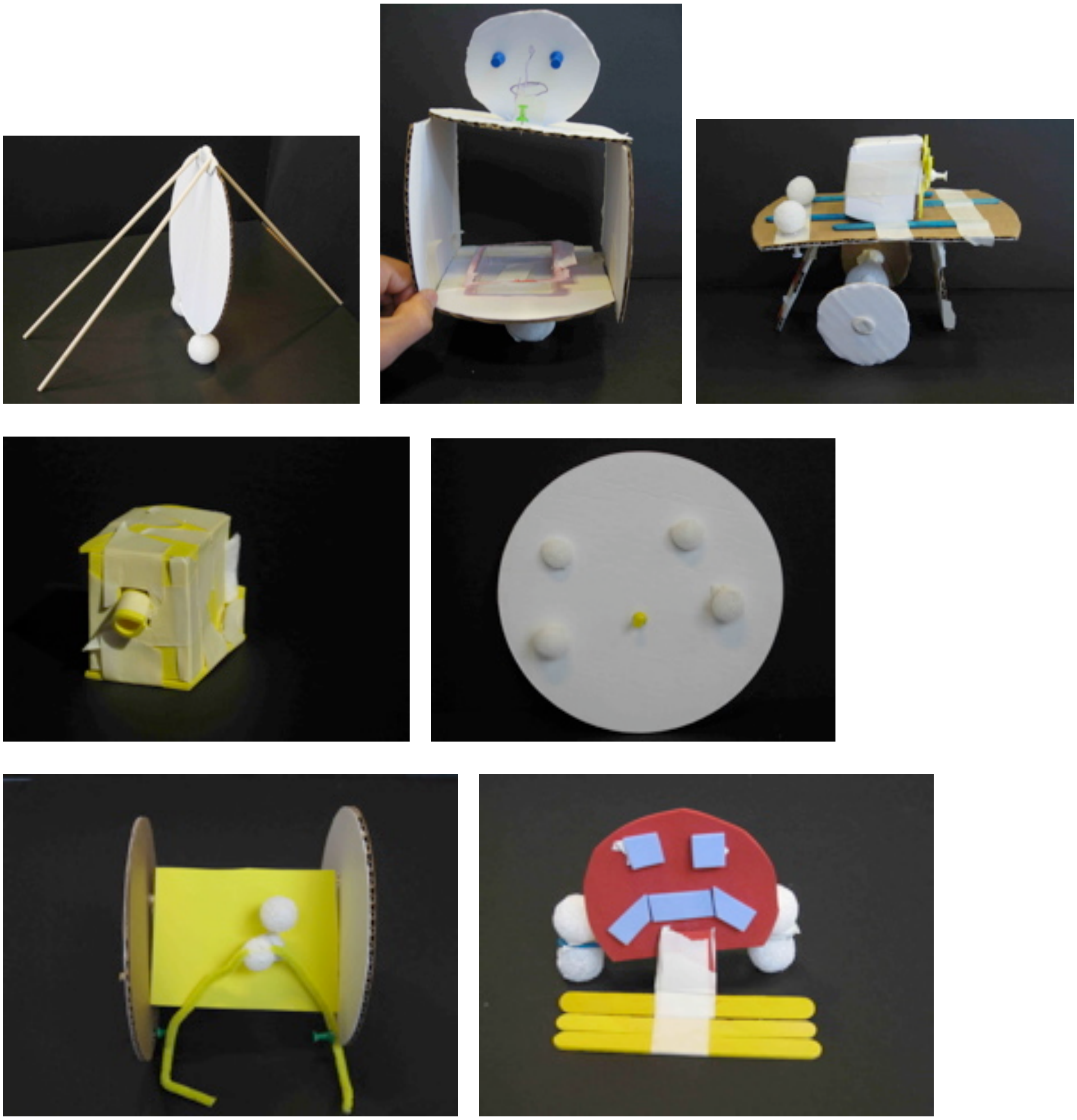


Figure 26. Design task solutions (post interview).

1st row (left to right): Allison, Chloe, Dakota. 2nd row: Gabrielle, Mia. 3rd row: Noel, Tracy.

Figure 27 displays the number of interaction/communication modes suggested by each girls' design solution. Common modes of interaction/communication included having the robot approach people, speaking an anti-smoking or anti-noise message (via the speaker), lighting up as a warning, or using lights to alert people to the robot's presence. Less frequent modes of interaction/communication included having the robot use bright lights to signal the police, presenting smokers with an ashtray to extinguish cigars, and having the robot sound an alarm when the level of smoke reached beyond a certain level. Three participants (Tracy, Allison, and Mia) designed their robot with more modes of communication/interaction during the post interview than the pre, three designed robots with the same number of interaction/communication modes during pre and post (Gabrielle, Chloe, and Dakota), and the remaining participant (Noel) designed a robot with fewer modes of interaction/communication on the post interview. However, as was the case in the creativity task, not all of these modalities were directly repeated from pre to post. The percentage of post interview solutions also present at pre interview were (for each participant, respectively): 33%, 0%, 0%, 50%, 50%, 66%, 50%[28].

[28] Categorization takes into account the difference in pre-post scenarios. For example, a robot designed to speak an anti-noise message in the pre and speak an anti-smoking message in the post has a repeated communication modality.

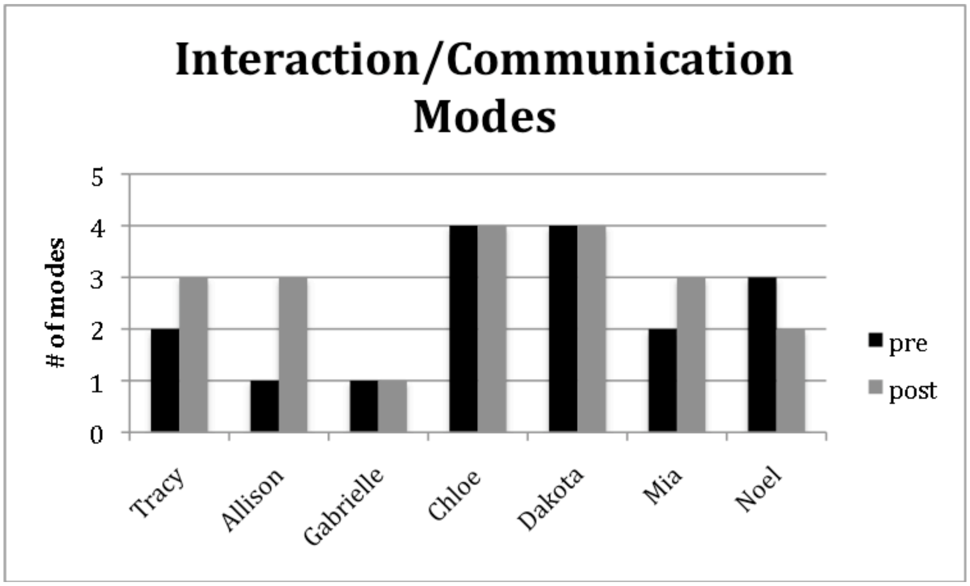


Figure 27. Number of interaction and communication modes suggested during design task

Only three solutions (one pre, two post) were specifically designed to induce emotion (see Figure 26 for Tracy's unhappy robot; other robots were meant to surprise people with sound [Gabrielle pre] or annoy them with an alarm [Mia post]).

All but three of the technology solutions developed were stand-alone robots. Two robots were designed to signal the police if the noise level reached an unacceptable limit (Dakota and Chloe pre solutions), and one was part of a network of smoke-detecting devices scattered throughout a park (Mia post solution).

4.2.2.5 Results: Design solution as an engineered system.

The most straightforward way to learn about the systems created during the design task is to understand their components. During the task and follow-up interviews, each participant was asked to describe her system and the parts required to build it. Transcripts of the design task were then analyzed for the presence of different types of entities (see Russ, Scherr, Hammer, & Mikeska, 2008). In a 'black box' technology like an electronic toy, some entities are visible (e.g., the toy's face, tail, or ears) and some entities are hidden (e.g., motors, sensors, and switches). The presence of entities in the latter category must be inferred from the system's behavior. In the design task, participants' descriptions of these types of entities are categorized as 'inferred.' Inferred entities can be mechanical, such as pulleys or gears, or technological, such as sensors, motors, lights, speakers, wires, wireless systems, or batteries. Inferred entities can also be computational, such as computers, microprocessors (e.g., 'chips' or hummingbirds), or computer programs. Two independent raters coded 20% of the transcripts for the presence of observable and inferred entities. Agreement on the presence and categorization of entities as observable, inferred – mechanical/technological, or inferred – computational, exceeded 85%. Figure 28 shows the number of inferred mechanical/technological and computational entities described as part of each participant's model.

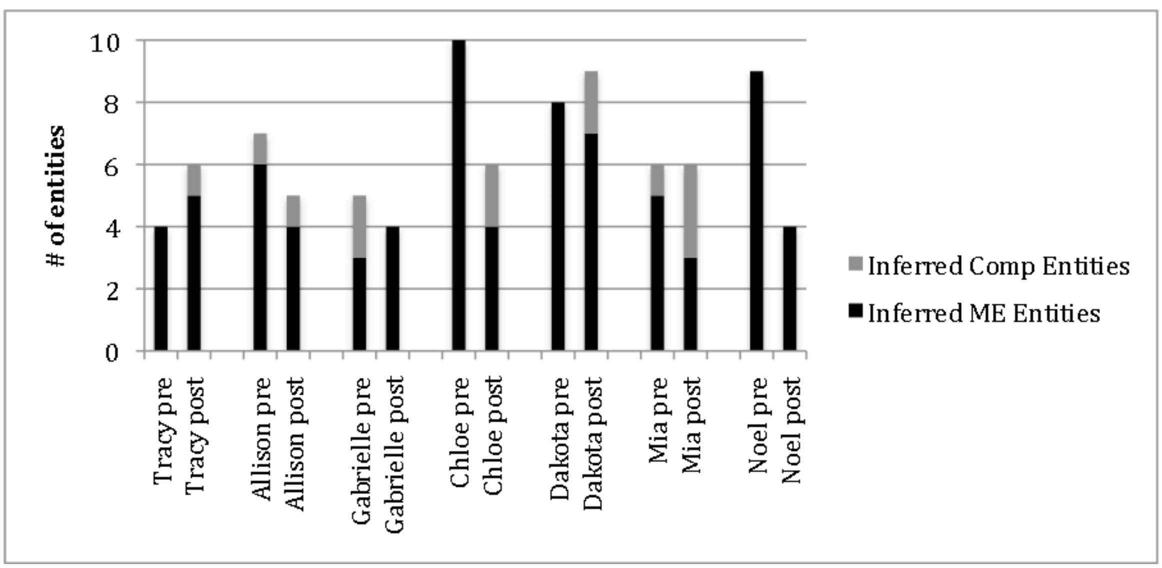


Figure 28. Number of inferred computational and mechanical/technological entities in participants' design task solutions

The number of inferred mechanical or technological entities decreased from pre interview to post interview for five of the seven participants (Allison, Chloe, Dakota, Mia, and Noel). A further examination of the data suggests two main reasons for this decrease. First, some participants described basic electronic parts during the pre design task (i.e., wires, batteries) that were not repeated in their descriptions at post interview. Second, some participants modeled simpler systems during the post interview than during the pre interview, and the simpler systems required fewer components (see 'feasibility' section below).

Inclusion of computational entities followed a different trend than the mechanical and technological entities – four out of seven participants (Tracy, Chloe, Dakota, and Mia) described more computational entities in the post interview than they did in the pre.

Design task transcripts were also coded for the presence of different types of relationships among system components and system behaviors. Entities and behaviors can have a *direct relationship* (e.g., the motor moves the wheels; smoke is detected by the sensor); they can also be part of an *indirect relationship* (e.g., the sensor senses smoke and then tells the wheels to move). The second case describes an input-output relationship, such that an input entity (the sensor) responds to an input behavior (smoke) and triggers an output entity (the motor) to produce an output behavior (movement of wheels). Conceptually, this relationship can be represented as follows:

Input Behavior (IB) → Input Entity (IE) →→ Output Entity (OE) → Output Behavior (OB)

If participants recognized the need for a computational entity as part of the system, such as a computer, program, or microprocessor (e.g., a hummingbird), the relationship could be represented in the following way:

IB → IE →→ Computational Entity →→ OE → OB

This schematic was used to identify four levels of increasingly sophisticated reasoning about the relationships between entities and behaviors: (Level 1) presence of an entity; (Level 2) a direct relationship between an entity and behavior; (Level 3) an indirect relationship between entities and behaviors, but only one entity is named; (Level 4) an indirect relationship, and two or more entities are named. Table 2 describes the application of this coding scheme to the design task transcript data.

Table 2. Coding categories for design task solutions

		SYSTEM COMPONENTS	
		Inferred Entities: Mechanical or Technological	Inferred Entities: Computational
LEVEL OF REASONING	Level 1: Presence of entity	*"these are both little **speakers**"* *"the **sensor** would go right here"*	*"they'd need a **hummingbird**"* *"they'd need to **program** it"*
	Level 2: Direct relationship between entity and behavior	*"the **sensor**… would tell if there was noise or not"* *"it could flash the **lights**"*	*"the **hummingbird** could fit right there… you could plug all of the parts into it, like the **speaker** and the **motors**."*
	Level 3: Indirect relationship between entity and behavior, only names one entity	*"if it hears a noise through the **sensors** – if it's a less sound it will turn towards the noise"*	*"you could **program** a routine into [the robot] so it would just keep doing the same thing, like sort of go this way, go that way… move back and forth"*
	Level 4: Indirect relationship between entity and behavior, names 2 or more entities	*"when the **sensor**… would sense something was near, the **speaker** would say 'please don't smoke'"*	*"probably **program** it to, when there's a certain amount of sound waves that the **sensor** is sensing that it will send the signal to the **light**"*

Design task transcripts were coded to determine the highest level of reasoning reached by participants when describing their systems; descriptions including an inferred computational entity were coded separately from those including only mechanical or technological entities (an additional column of ‘non-inferred’ or observable entities was also included in the original coding scheme but will not be reported here; observable entities included elements such as hooks, wheels, and building materials). Two raters independently coded 20% of the design task transcripts. Upon reaching mutual agreement about the presence of statements that contained relationships between entities and behaviors, the raters were 100% concordant in placing those statements at the appropriate level of reasoning.

Figure 29 displays the highest reasoning level reached by each participant for inferred mechanical/technological entities (left column) and inferred computational entities (right column). Levels of reasoning have been collapsed into low (levels 1 or 2) and high (levels 3 or 4) for ease of presentation.

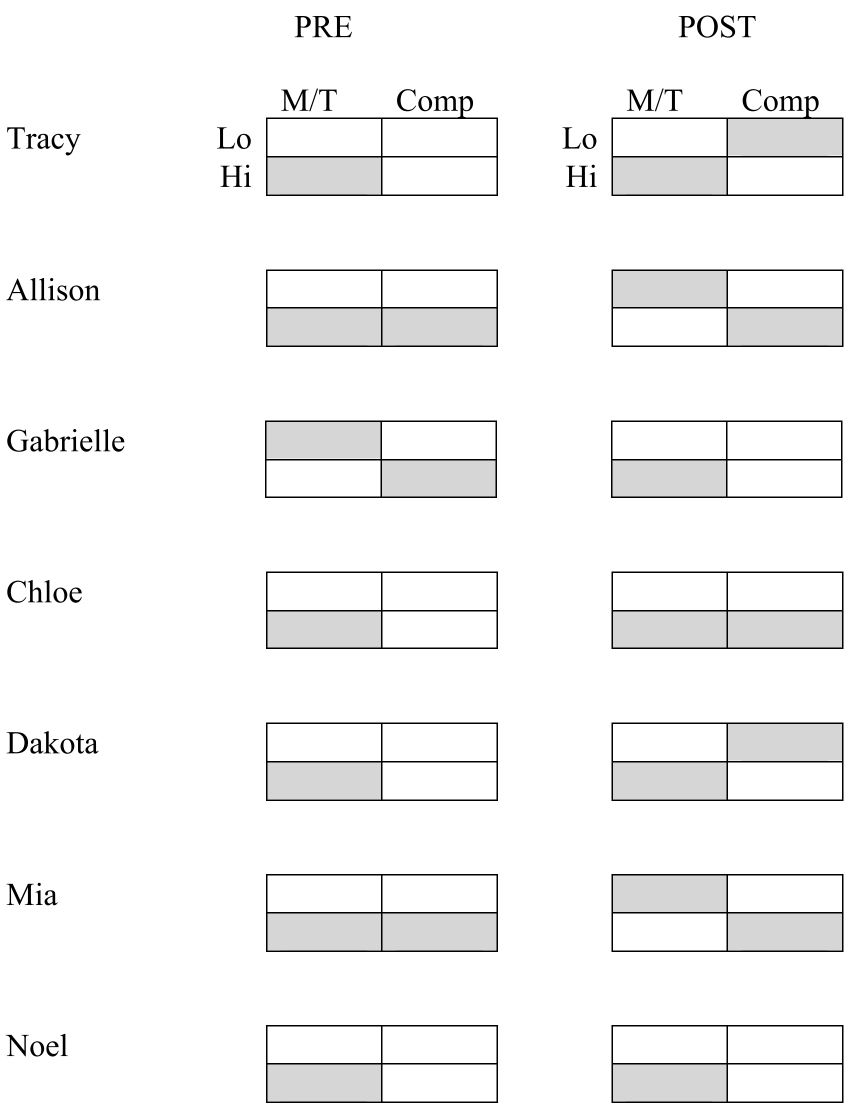


Figure 29. Highest level of reasoning reached for mechanical/technological inferred entities (left column) and computational inferred entities (right column) on the design task.

Rows represent low levels of reasoning (first row) and high levels of reasoning (second row).

The 'optimal' outcome in this coding scheme is for participants to reach the highest level of reasoning (bottom row) and be able to describe inferred computational entities (right column) in their design task solutions. All participants reached the highest level of reasoning at pre test. Thus, even before the workshop began participants were able to describe indirect entity-behavior relationships in their design task solutions, making it difficult to determine pre-post change for this dimension of the design task. Additionally, three participants (Allison, Mia, and Gabrielle) included inferred computational entities in their systems at pre interview, all at a high level of reasoning. At post interview, three additional participants (Tracy, Chloe, and Dakota) described the computational entities in their design task solutions.

4.2.2.6 Feasibility of design solutions.

Transcripts and models were also examined qualitatively to determine if there were differences in the feasibility of design task solutions at pre and post interview. The author was aided by two members of the Robot Diaries curriculum team (a robotics graduate student and a Robotics Institute staff member) in making these judgments.

Two trends towards increased feasibility can be discerned in the pre-post design task responses. One trend is towards simpler and more realistic systems at post test. A second trend is towards increased computational control at post test.

Two participants – Allison and Noel – implemented simpler design solutions at post interview than those proposed at the pre interview. Their solutions are summarized and discussed below.

> Allison (pre): A user will hold this system, which will help them locate the source of the loud noise. A sound sensor picks up sound, and then lights light up on a screen to indicate the location of the sound and also the current location of the user. As Allison explains it, "[the robot is] like a navigation system… and it could tell you where the noise is. So it's a little blips somewhere on the screen and you have a dot. And as you move, the dot moves…you need to find out where the noise is based on where you are or the noise is to try to go find the noise." She proposes that the system will be controlled by a 'chip,' that will send signals through the wires to light up the lights. *Parts required: lights/light bulbs, circuit boards, screen, battery, sensor, alligator clips/cords, a 'chip'. Direct relationships: (1) a battery powers the robot; (2) lights show up on the screen; (3) a sound sensor picks up sound. Indirect relationships: (1) light bulbs light up on the screen according to the user's location; (2) sound sensor picks up sound and the lights light up according to the location of the sound; (3) a chip sends signals through the wires to light up the lights.*

> Allison (post): "Maybe a law could get passed or like a rule or something that says smoking is prohibited in this park and the robot could go around with the sign and light up or something. Say, 'smoking is prohibited in this park' like at the entrance of the park." Allison further explains that the robot would be "programmed to move around the park in a specified route, displaying its sign. You could program a routine into it so it would just keep doing the same thing, like sort of go this way, go that way, go this way, go that way, go this way, move back and forth – stuff like that, so the sign gets noticed." Because the robot would move around on only 2 wheels, it would have metal supports to prevent it from losing its balance when it stopped. *Parts required: control panel, wireless signal system, motors, LED's, a program. Direct relationships: (1) LED's blink; (2) motors move the robot. Indirect relationships: (1) a program controls the movement of the robot.*

Allison's first design solution is modeled after a familiar consumer technology – a navigation/GPS system. Although she admits during her interview, "I don't know how those work," she is able to make estimations about the number of parts and types of relationships that would be required to build such a system.

There are some basic feasibility concerns with this solution. While a sound sensor could potentially distinguish between sound and a lack of sound, it would be difficult for a single sensor to determine *where* the sound was coming from. This would lend difficulty to her proposed indirect relationship between the sound sensor (which is supposed to locate sound) and the lights (which are supposed to communicate this information to the user). It is also not clear why this robot is necessary or even helpful, since the user holding the system would likely do a more accurate job of sensing and locating sound than would the robot. Finally, Allison does not include a mechanism for locating the person's whereabouts in her system – this might require the integration of an existing GPS system into her handheld device.

Allison's second design has more interaction and communication modes than the first, but is a simpler system utilizing fewer components. Unlike the sensor-based system she described during the first interview, this system is pre-programmed to move around the park and display a sign to park patrons. As Allison herself suggests, this solution is "pretty simple. That would be an easy robot to build." While this robot would require a program to control its movement, there are fewer indirect relationships between components than was the case in her first design. The major challenge to feasibility for this robot would be balancing on two wheels, although she attempts to rectify this problem by adding metal supports to the robot.

> Noel (pre): "It has six legs… and it walks. And this part (points to Styrofoam ball on top) looks around for, it hears the sound, it looks around for the person that's making it. And then this part shows a screen… and there's a speaker that says… to please be more quiet or leave the neighborhood." *Parts required: Screen, speaker, motors, electronic legs, recorder, wires, lights, battery, sensor. Direct relationships: (1) a recorder plays the message; (2) the message goes out of the speaker; (3) motors move the robot's legs; (4) a motor moves the screen; (5) lights light up the dark; (6) the sensor senses a person. Indirect relationships: (1) sensor senses where a person is and then the motors move the robot's legs towards the person; (2) the battery and a wire make the robot's head move around, looking for the noise maker.*

> Noel (post): This robot roams around the park and sprays perfume. "These are two big wheels that wheel around and this is a magnet. There's a magnet there and a magnet here that holds them together but when it wheels them, um, magnets break part and it just sticks. The magnet here breaks apart from that one and then when it stops again to spray, this hooks back because they're so strong." *Parts required: magnets, LED's, motors, rope. Direct relationships: (1) lights light the robot's way; (2) motors move the wheels; (3) rope pushes down on the lid of the perfume bottle (to spray perfume); (4) magnets hook/unhook to release the rope. Indirect relationships: (1) when the wheels stop the magnets attach. This action pulls the rope and sprays the bottle.*

There are a number of feasibility concerns with Noel's initial robot design, the largest of which is Noel's use of motors. Noel's design calls for one motor to control three of the robot's legs, while a second motor controls the other three legs plus the screen atop the robot. This proposal seems difficult to implement, particularly without the inclusion of gears or some other device to distribute the motion of the motors. Like Allison's initial design proposal Noel's robot also includes a screen, although it is not clear from her explanation what the screen would be used for. An additional feasibility problem can be found in Noel's use of the sensors to direct the robot to noisemakers. The problem here is similar to the one Allison faced in her first design solution, where a single sensor would be responsible for both sensing and localizing sound.

Noel's second (post) design solution presents a very different robot design. In this solution, she has used the motors in a more realistic way by having each motor control a single wheel. Noel spends a good portion of the design task thinking about her mechanism for spraying the perfume bottle, and while her idea is not entirely complete (it is not clear, for example, how the robot will start up again after spraying the bottle) her design process during the post task indicates her recognition that the physical mechanism(s) controlling the robot might require a bit more thought than provided in the pre design task.

While Noel's robots do not include any computational control, some other participants showed a shift from mechanical to computational control in their post design solutions. Mia's design solution provides an example of this trend. Her pre and post design solutions can be summarized in the following way:

> Mia (pre): This robot will respond to sound by lighting up and then issuing a verbal message asking people to be quiet. As Mia describes, "with the sensor, when it senses it gets too loud it will turn on the light for a few seconds and then if it, if the sensor senses (inaudible) even if the light for like a minute or something then it will make the sound, the recording go."

> Mia (post): This robot is similar to the pre design task solution. "If there was too much smoke… the lights would go on… and then it would give them a minute to bring the smoke down and then um, if that didn't happen the…speakers would say um, please stop smoking and then, if there wasn't, if the smoke wasn't down (inaudible) five minutes then um, the alarm would go off and it would keep going off until people brought the smoke down."

While her solutions to the pre and post design task are quite similar, Mia provides a different description for how each system will work. When asked during the pre interview how someone could make her proposed system, Mia responds:

> Mia: I'd probably attach wires from like the sensor to the light and, and I'd have to have something that would have it go to the light first but not go to all the others until a couple minutes later so if the light doesn't work then it will-, if the sound doesn't get quieter then it will send it to the spe-, the, send signals to the speakers through the wires. So and

then it would have to have speakers and wires attached to all the, going from the sensor to all the speakers too.
Researcher: So how would you do that, how would you make it so that the light went on first and then the speakers only went on later?
M: I'd probably, I'd probably actually have to have a motor so it would send, the signals to the light first, know to send the signal to the light first and then to the others. I need a motor to make the light go on probably too.

[later in the interview]

R: So what other challenges would someone face in building this?
M: Um, I think another challenge would be, um, having the sensor sense when there's too much sound and not when there's just any sound.
R: … How would you do that do you think?
I: Probably program it to, when there's a certain amount of sound waves that the sensor is sensing that it will send the signal to the light.
R: Cool. And how would you, I can't remember if you told me this already, how would you solve the problem of having this go on first and then the speakers?
I: I'd probably – use a motor to send it there first and then use another motor to send it to the-.

However, when asked a similar question during the post interview, Mia replies:

M: And then they'd need like a hummingbird and then they'd need to program it….
R: And what would the hummingbird do?
M: Um, send it to the computer so they could program it at first… you need to program when there's too much smoke the lights to come on and (inaudible) give it a certain period of time. And then the speakers to say please stop smoking and then another period of time and if there was um, still (inaudible) a lot of smoke then the alarm would go off and then it would stop when, um, there wasn't the, a large amount of smoke.

In the first excerpt, Mia proposes using a motor to turn on the lights and sequence the lights and speaker. Interestingly Mia does suggest programming her first robot, but she limits the programming to that necessary to activate the sound sensor and signal the lights. However, in the post design task she suggests a computational solution (i.e., a program) to the sequencing problem as well.

Chloe makes a similar transition in her descriptions of her pre and post design task robots. Chloe's pre and post design solutions can be summarized as follows:

Chloe (pre): "It's like a night patrol, after like nine o'clock at night it will go out and it will just go on the sidewalks or on the road and it will go around. If it hears a noise through the sensors, if it's a [quieter] sound it will turn towards the noise and flash [neon signs at] whatever sound that was and if it's a [louder] sound it will flash even brighter and [the neon signs] will say, 'please quiet down'… and then if it sees something that's making a really really loud noise and won't stop it will send a radio signal to like police or a radio tower." There is also a speaker on the robot that will broadcast a recorded message to 'please slow down' when cars race past.

Chloe (post): "It would be on wheels, so it could move around the park, and it had a smoke detector in it. Like that would be the sensor, and so it would sense the smoke and it would, it knew where that smoke was coming from, could track the source, and go up to it and say 'please don't smoke'. And there would be like a bin coming out of it, you know where you put the cigars when you're done with them."

When Chloe is asked to explain how her sensors would work on her initial robot design, she proposes a mechanical mechanism:

R: Okay, so how does it sense the noise?
Chloe: Through these [touches Styrofoam balls which represent sensors] and when it hears it, it goes through the – it like intakes the sensors that are like kind of like intake speakers and it – once a noise goes through here of a certain volume it will activate. It has to be like more than such volume to activate this one, and it can't be any more. If it's any more than that it will activate this one. [points to two neon signs?]
R: Okay. So, okay. So, how can you set up sensors to do that?
C: … You can have sound sensors like how it is on a burglar's alarms and stuff and it would intake the sound and if it's not like there's somebody walking around it would go to the neon signs and it like it would move which would flip the switch for the neon sign and then when the noise quieted down, it would flip a switch and the neon sign would go off. [I pushes down on popsicle stick/sytrofoam ball sticking out of robot]…It would flip the switch on and off.
R: For the neon sign?
C: Yea.

However, when asked how someone would create her robot during the post interview, Chloe suggests using computational entities to control the lights in her robot:

C: They would have to add the head and put in the LED's. Find a place to put like a hummingbird and then they would probably put the sensor and then the waste basket last.
R: Why would they need the hummingbird?
C: Well so the LED's could work, or like a computer inside the robot.

Neither the trends towards simplicity or computational control were universal. While both Dakota and Tracy mention computational entities in their post design solutions, neither girl is as explicit about implementing computational control mechanisms as the two cases described above. Gabrielle moved in the opposite direction, describing computational control mechanisms in her first design task solution but not her second. With regard to simplicity, Dakota's design task solution was intricate and complex in both the pre and post interviews, while Tracy's solution may even increase in complexity at post interview as she moves from a stationary to a mobile robot.

Nonetheless, these small trends towards simplicity and computational control are interesting outcomes, particularly for some of the less experienced participants like Allison and Noel. It is possible that participating in the workshop helped to influence their ideas about what constitutes a feasible and realistic design for a complex technological system.

4.3 TECHNOLOGY CONTENT KNOWLEDGE

Technology content knowledge was measured in three different ways. Participants were assessed regarding their knowledge of technological components, knowledge of the design process, and asked to make inferences about the functioning of two technological systems – a consumer technology and a robotic art installation.

4.3.1 Understanding Technological Systems: Consumer Technology

4.3.1.1 Task Description.

A commercially available electronic toy, iDog, was used for this task (see Figure 30). The iDog retails for approximately $20. There are three ways of interacting with the iDog – pulling its tail, pushing its nose, or activating the motion sensor atop its head. In response, the iDog can growl, move its ears, move its head, and light up its face. Participants were invited to touch and explore iDog prior to answering questions about how it worked. One participant (Noel) reported owning an iDog, and several other participants reported having seen an iDog before.

Figure 30. The iDog

After participants had an opportunity to familiarize themselves with iDog, they were asked a series of questions about it:

- What do you think it is, or does?
- How do you think it works?
- What's inside?
- Do you think the iDog can learn?
    - [If no or I don't know] how could you find out if it could?
    - [if yes] How do you think it learns? How could you tell if it had learned?
- Does the iDog know what you're doing? If so, how?
- Do you think you could take it apart? How?

4.3.1.2 Task Coding.

Coding for this task utilized a simplified version of the schematic introduced during the design task coding description. The two dimensions of interest were the identification of entities (inferred – mechanical/technological, and inferred – computational; an additional level of observable entities was also included in the original coding scheme but will not be reported here) and level of reasoning (presence of entity/direct relationship or indirect relationship). Table 3 describes the application of the coding scheme to the iDog task data. Two independent raters coded 20% of the data to determine which system components and levels of reasoning were represented in each task transcript. Inter rater agreement was 100%.

Table 3. Coding categories for Understanding Technological Systems tasks

		SYSTEM COMPONENTS	
		Inferred Entities: Mechanical or Technological	Inferred Entities: Computational
LEVEL OF REASONING	Presence of Entity OR Direct relationship between entity and behavior (levels 1 and 2)	*“his ears move with little servos”* *“it has a little speaker that makes it make noise”*	*“it might be programmed”* *“there might be something like a hummingbird inside it”*
	Indirect relationship between entity and behavior (levels 3 and 4)	*“when you press a button or pull its tail, it activates the servos to move and the lights to light up”*	*“you could program it to… put different patterns on the lights”*

4.3.1.3 Results.

Figure 31 displays the highest level of reasoning provided by each participant for inferred mechanical/technological entities (left column) and inferred computational entities (right column).

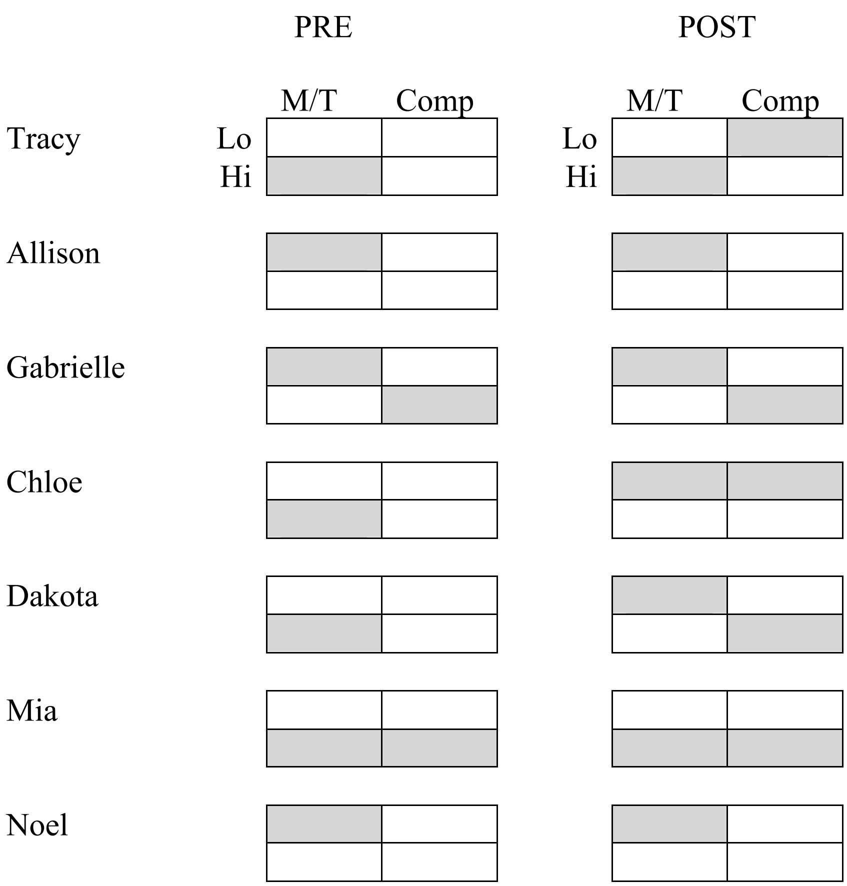


Figure 31. Highest level of reasoning reached for mechanical/technological inferred entities (left column) and computational inferred entities (right column) on the iDog task.

Rows represent low levels of reasoning (first row) or high levels of reasoning (second row).

Even at pre interview, five out of seven participants were able to articulate at least one indirect relationship in the iDog. Neither Allison nor Noel did so during the pre or post interviews. Regarding the recognition of inferred entities, all participants were able to name inferred mechanical or technological entities in the iDog at pre interview (commonly named entities at pre test included motors, speakers, and sensors). Two participants – Gabrielle and Mia – recognized the need for unseen computational entities to control the iDog during the pre interview. Three additional participants – Tracy, Chloe, and Dakota – were able to do so during the post interview.

4.3.2 Understanding Technological Systems: Robotic Art Installation

4.3.2.1 Task Description.

Participants viewed a video of a robotic art installation, *Birds Leap to Fly*[29]. The installation consisted of two abstract birds, each supported by a balloon (see Figure 32), and was installed in a storefront window. Users interacted with the installation by placing their hands on sensors attached to the glass storefront – touching the glass triggered the bird's legs to move, which pushed the bird up into the air. Participants watched a 96 second video of the installation, which included close-ups of the bird and balloon, and footage of pedestrians interacting with the installation.

Figure 32. Birds Leap to Fly robotic art installation

[29] *Birds Leap to Fly* was created by artist Ian Ingram. The video is available on-line: http://www.ingramclockworks.com/BirdsLeapToFly_640x480_web.mov

After watching the video, participants were asked to explain how the installation worked. Explanations were prompted via a series of questions:

- Talk to me a little bit about what you saw in the video. What was happening?
- Do you think it's interesting? Why or why not?
- How do you think this technology works? What parts are inside?
- Why do you think the creator made this?
- If you could ask the creator anything you wanted to about this technology, what would you ask him?
- Sometimes technology can be expressive. Do you think the creator is trying to say something or express something with this technology? What are they trying to say?
- Do you think this is a robot? Why or why not?

4.3.2.2 Task Coding.

Coding for this task utilized the same components/levels of reasoning schematic as the iDog task. Two independent raters coded 20% of the data to determine which system components and levels of reasoning were represented in each task transcript. Inter rater agreement was above 85%. Participants' answers to the question, 'Do you think this is a robot? Why or why not?' were also coded separately. Responses to this question were categorized in three ways: action (i.e., the installation is/is not a robot because of what it does/does not do, such as move), control (i.e., the installation is/is not a robot because it can/cannot be controlled or programmed), and agency (i.e., the installation is/is not a robot because it can/cannot do things on its own, such as sense or respond to the environment). Two independent raters coded 20% of the data with respect to this question. Inter rater agreement for categorizing responses was 100%.

4.3.2.3 Results.

Figure 33 displays the highest level of reasoning provided by each participant for inferred mechanical/technological entities (left column) and inferred computational entities (right column)[30] in *Birds Leap to Fly*.

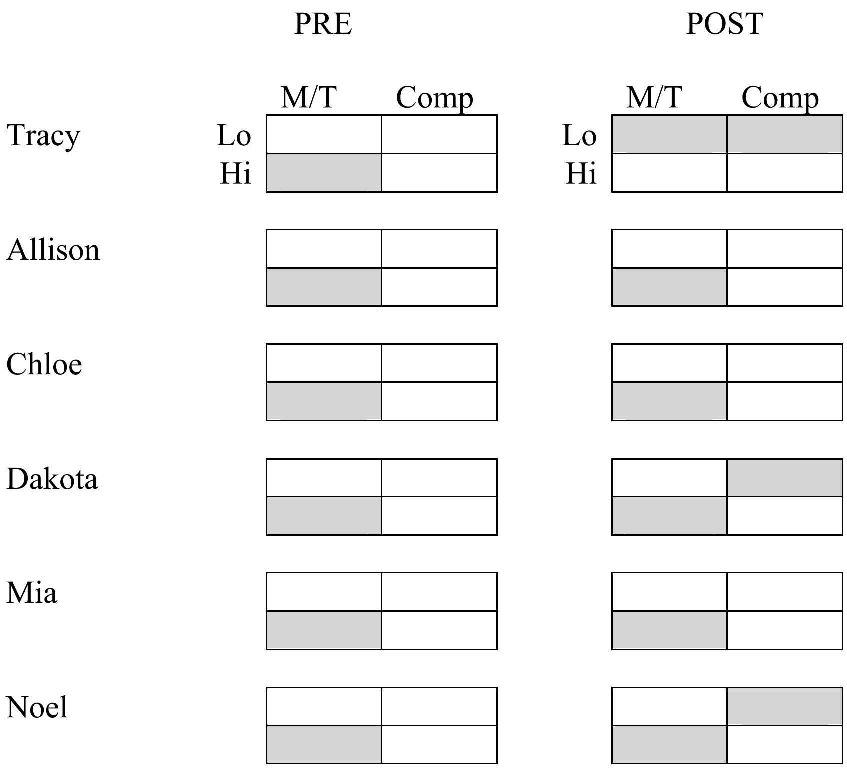


Figure 33. Highest level of reasoning reached for mechanical/technological inferred entities (left column) and computational inferred entities (right column) on the *Birds Leap to Fly* task. Rows represent low levels of reasoning (first row) or high levels of reasoning (second row).

All participants were able to articulate at least one indirect relationship in the *Birds Leap to Fly* system at the pre interview. While every participant was able to identify inferred mechanical or technological entities at pre test (commonly recognized entities included sensors

[30] Due to time constraints at the post-test, Gabrielle was not asked this question. Her data have been removed from this analysis.

and motors), no participants identified an inferred computational entity at the pre interview. Three participants – Tracy, Dakota, and Noel – identified a computational entity in the post interview.

In response to the question of whether the *Birds Leap to Fly* system was a robot, two participants (Tracy and Mia) said it was a robot at the pre interview. The remainder of the participants either said it was not a robot, or gave equivocal answers about its status. Participants gave the following reasons for their responses: it can be controlled (3 participants), it has agency (2 participants), it performs actions (1 participant). At post interview, four participants (Tracy, Chloe, Mia, and Noel) said the system was a robot. Participants gave the following reasons for their responses: it has agency (5 participants), it can be controlled (3 participants) (some participants gave more than one response).

Across the two 'Understanding Technical Systems' tasks, four children (Tracy, Chloe, Dakota, and Noel) moved from not recognizing the presence of a computational entity in either system at pre interview to recognizing this presence in at least one system at post interview. Two children (Gabrielle and Mia) recognized the need for a computational entity in at least one system at the pre interview. Only Allison did not recognize the computational entities in either system at pre or post interview. In terms of believing that the *Birds Leap to Fly* installation was a robot, more children believed this to be true at the post interview than at the pre interview. Interestingly, more participants believed that agency was an important factor in making something a robot at the post interview than at the pre interview (2 out of 6 participants claimed agency as a defining factor of a robot at the pre interview, while 5 of 6 claimed it at the post interview).

4.3.3 Knowledge of Technology Components

4.3.3.1 Task Description.

Participants' familiarity with and knowledge of technology components was assessed in several ways. Participants were first shown six technology components that would be used in the Arts and Bots workshop (an LED/light, motion sensor, servo/motor, alligator clips, battery pack, and switch) and asked to identify each component. They were then asked to describe two of the components in detail – a sensor and an electric motor – and give examples of items that included these two parts.

4.3.3.2 Task Coding.

Familiarity was assessed by counting the number of components participants were able to correctly identify. Participants' descriptions of a sensor were coded on a 3-point scale which awarded one point for talking about the types of things a sensor could sense (e.g., motion, sound); two points for explaining that a sensor responds to changes in environmental stimulus (e.g., 'a light sensor responds to changes in light'); and three points for also giving a technical description of how a sensor works, either by explaining the triggering mechanism (e.g., 'a beam of light goes across the table, and if the beam of light is broken the sensor will go off') or explaining that a sensor generates/sends an electrical signal into a system. Descriptions of the electric motor were coded on a 2-point scale, with participants receiving full credit for explaining that electricity spins the motor. Participants were assigned a score of 0 if they were unable to answer the question. Two independent raters coded 20% of the data and reached 100% agreement on both code assignments and the presence of an example for the sensor and electric motor questions.

4.3.3.3 Results.

Only Dakota was able to correctly identify all six of the technology components at the pre interview. The remaining participants all identified the battery holder, switch, and light bulb (LED) at pre interview, but none (except Dakota) were able to identify the sensor. In addition, Mia and Noel were unable to identify the alligator clips; Tracy, Chloe, and Noel were unable to identify the servo (motor). Noel identified the fewest components overall – she was unable to label the alligator clips, sensor, or servo at pre interview. By the time of the post interview, all of the participants were able to label those components they did not recognize at the pre interview[31].

Figure 34 shows participants' pre and post interview scores for the sensor definition. One participant (Gabrielle) answered at ceiling during the pre interview. Among the remaining participants, two increased their scores from pre to post interview (Tracy and Mia), three remained the same from pre to post interview (Chloe, Dakota, and Noel), and one decreased her score from pre to post interview (Allison). All participants were able to give an example of a technology item that included a sensor at both pre and post interview. Examples included automatic lights, smoke detectors, and burglar alarms.

[31] Gabrielle was not shown the battery holder or switch at post interview. However, she correctly identified both of these items at pre interview.

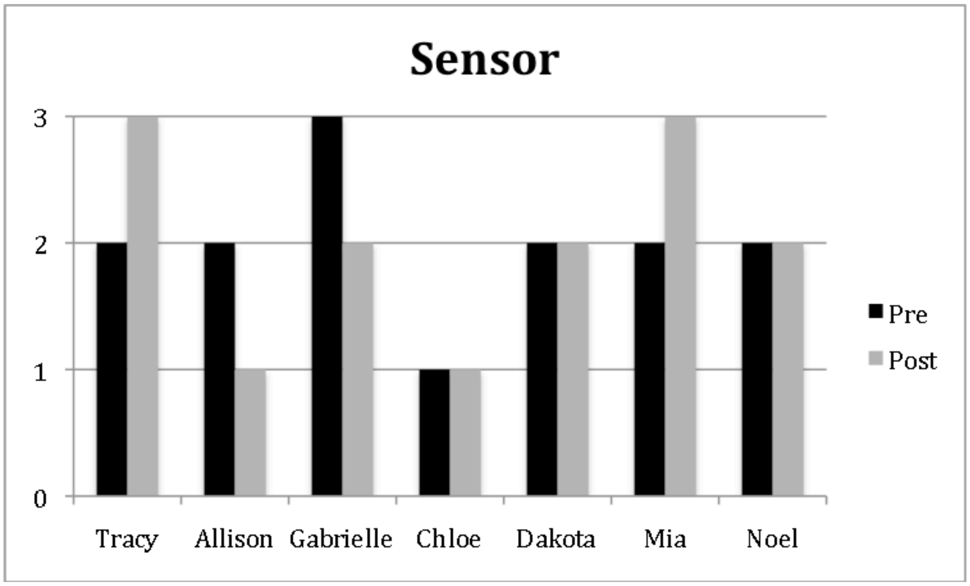


Figure 34. Participants' pre-post scores for sensor definition

Figure 35 shows participants' pre and post interview scores for the electric motor definition. Four participants answered at ceiling during the pre interview. Of the remaining three, two increased their scores from pre to post interview (Dakota and Mia) and one remained the same (Noel). All participants were able to give an example of a technology item that included an electric motor at both pre and post interview. Examples included a dishwasher, blender, and motorized toys.

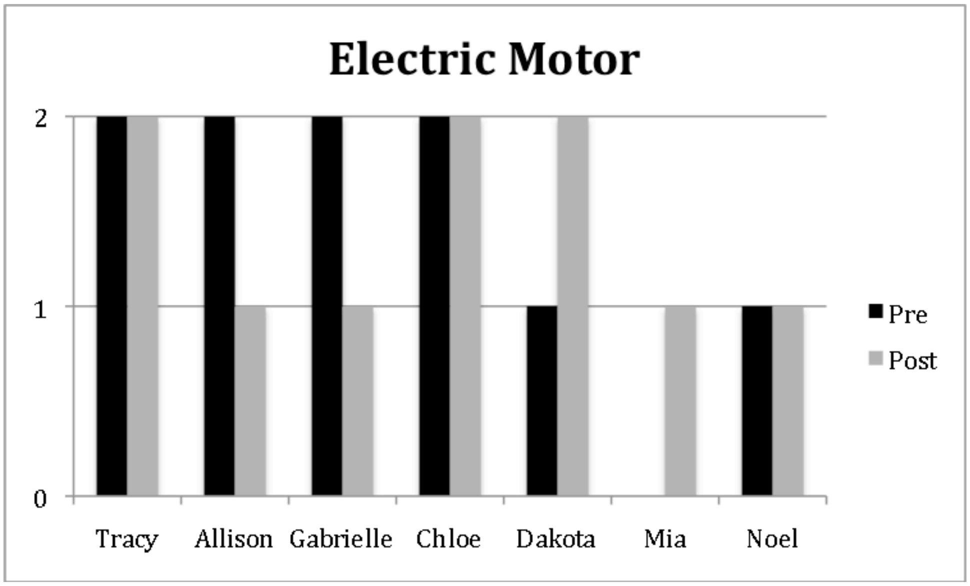


Figure 35. Participants' pre-post scores for electric motor definitions

4.3.4 Design Process Knowledge

4.3.4.1 Task Description.

Design process knowledge was assessed by asking participants to think about a technology they use often and talk about how it was invented. Ideas about invention were prompted through a series of probes (e.g., 'once someone decided they were going to make a __, what did they need to do next?', and 'how did they know it would work?'). Each participant was asked about the same technology during the pre and post interview.

4.3.4.2 Task Coding.

For the purposes of this task, the product design process was defined as a series of steps:

- Defining the problem
- Research
- Prototyping

- Testing
- Evaluating
- Re-designing/re-building to fix problems
- Gather/collect Feedback
- Documentation/Communication

This definition of the design process was influenced by a number of sources, including the design process presented in the Robot Diaries curriculum, the design process as presented by the instructors in class (which differed slightly from the process presented in the written curriculum materials), and outside sources (e.g., ITEA, 2002).

Design process knoweldge was coded by examining each task transcript for evidence of these steps. The 'testing', 'evaluating', and 're-designing' stages were collapsed into a single coding cateogry, due to the difficulty of distinguishing between comments about these three stages. However, participants could be given credit for commenting on a general 'testing, evaluation, re-designing' process (e.g., "They would probably have to figure out what they did wrong and go step by step to see what part didn't work and where and how they can fix that") or for commenting on the process in the context of the specific technology they were describing (e.g., "I think they had to experiment… with different kinds of microchips like sizes wise and how much power would need to fuel the microchip and the screen"). Two raters independently coded 20% of the data for the presence of each of the design process steps. Reliability was 100%.

4.3.4.3 Results.

Four of the participants answered the design process question with respect to an iPod or MP3 player, two answered with respect to a digital camera, and one answered with respect to a Play Station 2. Figure 36 shows the number of steps mentioned by each participant during pre and post interview. Figure 37 indicates the frequency of mention for each step during pre and post interview.

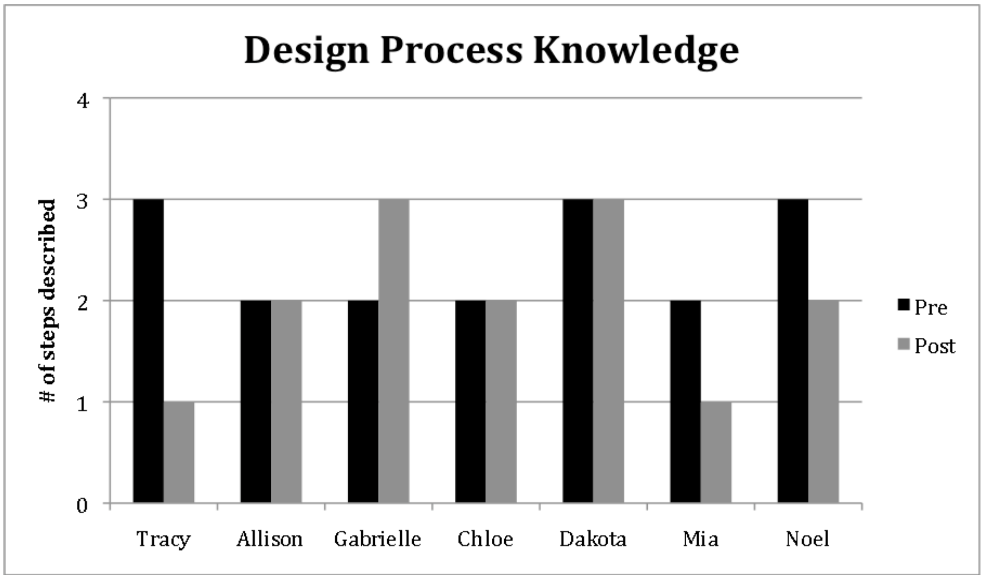


Figure 36. Changes in pre-post design process knowledge by participant

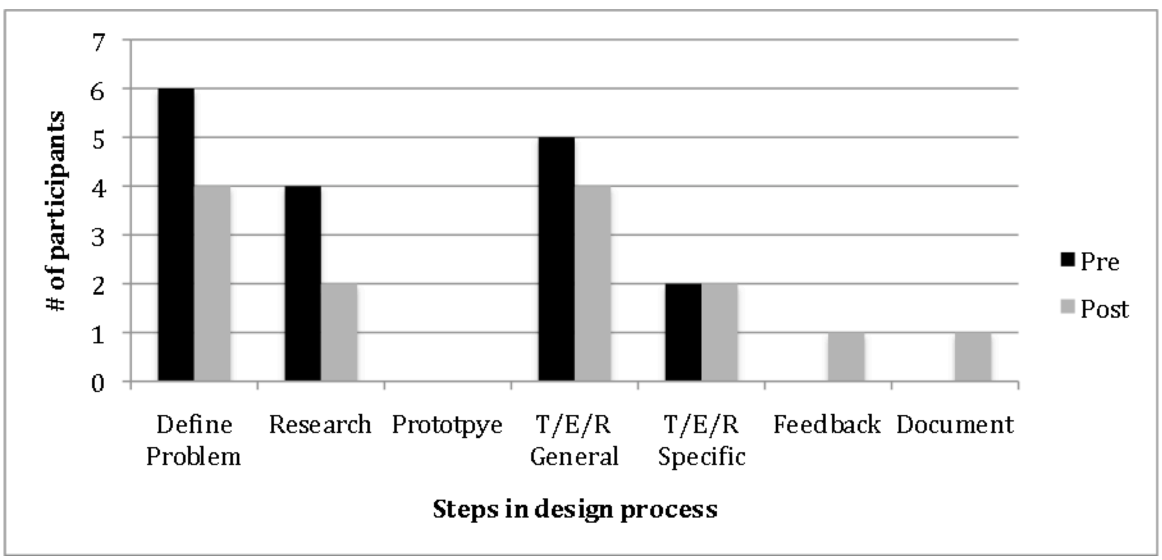


Figure 37. Changes in pre-post design process knowledge by step in design process

Mentions of design process steps increased for one participant (Gabrielle), decreased for three participants (Tracy, Mia, and Noel) and remained stable for three participants (Allison, Chloe, and Dakota). The majoirty of participants were aware of the 'defining problem', 'research', and 'testing/evaluation/re-design' steps at the pre interview. No participants stated that prototyping was part of the design process, and few participants recognized that gathering feedback or documentation were part of the process, even at the post interivew.

4.4 SUMMARY OF PRE-POST RESULTS

Pre- and post- workshop measures were used to assess gains in three primary areas: confidence and interest, knowledge, and creativity. This summary of results focuses on pre-post change with respect to robots and techology.

4.4.1 Confidence and Interest with Respect to Technology

Table 4 summarizes participants' pre and post workshop responses to questions about their confidence to engage with computers, robots, and everyday technology.

Table 4. Summary of pre-post changes in confidence

Participant	Confidence: Everyday Technology	Confidence: Computers	Confidence: Robots
Tracy	+	~	+
Allison	~	+	+
Gabrielle	-	-	+
Chloe	*	*	+
Dakota	+	+	+
Mia	-	+	+
Noel	-	~	+

+ indicates an increase in confidence scores from pre to post; - indicates a decrease in confidence scores from pre to post; ~ indicates no pre/post change; * indicates ceiling at pre *and* post survey. See Figure 17 for details.

All participants showed an increase in their confidence at making robots, while only a few participants showed change in their confidence to engage with computers or everyday techology. However, at pre survey the majority of participants (five out of seven) rated their confidence to engage with robots as lower than their confidence to engage with either computers or everyday technology. By the time of the post survey, six out of seven participants rated their confidence to engage with robots as equal to or higher than their confidence to engage with other types of technology. This suggests that the workshop helped the majority of participants become as confident with robots as they are with other types of (more familiar) techology, thereby expanding their range of 'comfortable' technologies.

Table 5 summarizes participants' pre and post workshop responses to questions about their interest in computers, robots, and everyday technology.

Table 5. Summary of pre-post changes in interest

Participant	Interest: Everyday Technology	Interest: Computers	Interest: Robots
Tracy	+	~	+
Allison	-	-	-
Gabrielle	-	-	-
Chloe	*	*	*
Dakota	+	+	~
Mia	*	-	*
Noel	+	+	+

+ indicates an increase in interest scores from pre to post; - indicates a decrease in interest scores from pre to post; ~ indicates no pre/post change; * indicates ceiling at pre and post survey. See Figure 19 for details.

Participants did not show any global increase in their level of interest with technology. However, as noted earlier this group of participants began the workshop with higher than average ratings of interest in comptuers (as compared to Mercier et al., 2006). Unlike their confidence ratings, all participants rated their level of interest in robots as equal to or higher than their interest in other types of technology at pre survey. Still, some participants did report an overall increase in their level of interest with respect to technology – Tracy, Dakota, and Noel all reported increases for at least two out of the three technology subscales.

4.4.2 Robot Knowledge

Table 6 presents a summary of participants' pre-post learning gains on the robot knowledge measures.

Table 6. Summary of pre-post changes in knowledge

Participant	Parts	Sensor	Electric Motor	System Reasoning[a]	System Components[b]
Tracy	+	+	*	*	+
Allison	+	-	*	*	*
Gabrielle	+	*	*	*	*
Chloe	+	~	*	*	+
Dakota	*	~	+	*	+
Mia	+	+	+^	*	*
Noel	+	~	~	*	+

+ indicates an increase in knowledge score from pre to post; - indicates a decrease in knowledge score from pre to post; ~ indicates no pre/post change; * indicates ceiling at pre survey; ^ indicates a score of 0 at pre survey. See Figures 29, 31, 33, 34, and 35 for details.

[a] 'System reasoning' is a compilation score drawn from three tasks: iDog, *Birds Leap to Fly,* and the design task. Participants are considered at ceiling if they reached the highest level of reasoning on at least one of these three tasks.

[b] 'System components' is a compilation score drawn from three tasks: iDog, *Birds Leap to Fly*, and the design task. Participants are considered at ceiling if they described computational components in at least one of these three tasks. A plus sign indicates an increase in knowledge at post test (i.e., including a computational component in the system description on at least one of the three tasks).

The first three results columns represent participants' performance on the technology components measures. The last two columns represent a compilation of participants' performance on questions related to the three robotic systems – iDog, *Birds Leap to Fly*, and robots created during the design task. Participants are considered at ceiling on these tasks if they reached the highest level of reasoning or components description on at least one of the three systems-related tasks. A plus sign indicates change in a positive direction on at least one of the three tasks.

Across the robot knowledge measures, there were 19 opportunities for participants to demonstrate learning (i.e., instances where participants were not at ceiling on the pre interview). Of those 19 instances, 14 showed positive change. The remainder showed no change or change in a negative direction. Tracy and Mia demonstrated the greatest change in their robot knowledge from pre to post interview.

Each participant showed learning gains on at least one of the three technology components measures. The majority of participants were better able to identify technology components after the workshop experience. However, few participants showed change in their ability to describe the sensor. This may be because the sensor was introduced towards the end of the workshop, and participants only had a part of one workshop session to use the sensor before they began working on the play.

All of the participants were able to describe at least one of the robotic systems at the highest level of reasoning during the pre interview. Three participants – Allison, Gabrielle, and Mia – were able to describe computational entities in at least one of the systems during pre interview. All four remaining participants were able to do so during the post interview.

While participants' recognition of the need for computational entities improved for the group overall, it may be the case that some participants developed a more complete understanding of this issue than others. For example, of the four participants who did not mention computational entities at all during the pre-interview, three of them – Tracy, Chloe, and Dakota – included computational entities in both their descriptions of existing robotic systems and the robot they modeled in the design task at post interview. Noel followed a different pattern, recognizing the need for a computational entity in the robotic art installation but failing to include one in her own design task solution. Similarly, of the three participants who mentioned computational entities at the pre interview, Gabrielle and Mia both included such entities in their design task solutions and the iDog. However, Allison only included computational entities in her design task solution (this was true at both pre and post interview).

While both Noel and Allison seemed to finish the workshop with an incomplete understanding of the need for computational entities, they showed other gains on the design task. Each of these participants described design task solutions during the post interview that were simpler and more feasible that those described at pre interview. This may indicate an additional step in their developing understanding of how complex technological systems function.

4.4.3 Robot Creativity

Table 7 presents a summary of participants' responses to two tasks assessing their creativity with respect to robots. The first column displays pre-post change for the number of responses generated to the robot privacy scenario in the creative uses task. The second column displays pre-post change for the number of interaction or communication modes included in participants' descriptions of their design task solutions.

Table 7. Summary of pre-post change in creativity

Participant	Robot Solution (Privacy)	Int/Comm Modes
Tracy	+	+
Allison	-	+
Gabrielle	-	~
Chloe	~	~
Dakota	+	~
Mia	~	+
Noel	-	-

+ indicates an increase in number of solutions/modes from pre to post; - indicates a decrease in the number of solutions/modes from pre to post; ~ indicates no pre/post change. See Figures 23 and 27 for details.

Of the 14 opportunities to show change on the robot creativity measures, five indicate change in a positive direction, four indicate change in a negative direction, and five indicate no change. Only Tracy showed improvements on both of these tasks. As a whole, this group of participants had no difficulty in generating creative solutions to the scenarios at pre interview. However, the workshop did not seem to encourage additional gains in this area.

4.4.4 Overall Summary

Table 8 presents a summary of participants' overall performance on the pre-post assessments.

Table 8. Overall summary of participants' performance on pre-post measures.

Participant	Knowledge Gains[a]	Robot Creativity Gains[b]	Change in Interest[c]	Change in Confidence[c]
Tracy	3/3	2/2	Increase	Increase
Allison	1/2	1/2	Decrease	Increase
Gabrielle	1/1	0/2	Decrease	Decrease
Chloe	2/3	0/2	No change	No change
Dakota	2/3	1/2	Increase	Increase
Mia	3/3	1/2	No change	Increase
Noel	2/4	0/2	Increase	No change

[a] The first number in the 'Knowledge Gains' column summarizes participants' gains on 5 knowledge assessments: parts, sensor, electric motor, system reasoning, system components (see Table 6 for details). The second number in this column indicates the number of knowledge measures (out of 5) where participants were not at ceiling at pre test. For example, Allison's score of 1/2 indicates that she had an opportunity to show gains on 2 of the knowledge measures (i.e., she was not at ceiling for two of the knowledge measures at pre-test). Of those 2 measures, she showed gains on one of them.
[b] The 'Robot Creativity Gains' column summarizes participants' gains on the 'robot privacy solution' and 'interaction/communication modes' creativity measures (see Table 7 for details).
[c] The 'Change in Interest' and 'Change in Confidence' columns summarize participants' responses to interest and confidence self-ratings across the robot, computer, and everyday technology subscales. An entry of 'increase' indicates that a participant's confidence/interest scores increased on at least 2 of the 3 subscales. An entry of 'decrease' indicates that participant's confidence/interest scores decreased on at least 2 of the 3 subscales. An entry of 'no change' indicates no consistent pattern of change across the three subscales.

This table suggests that Tracy and Dakota experienced the largest overall gains from the workshop. Each of these participants showed increases in confidence, interest, knowledge, and creativity. Allison and Gabrielle appeared to show the smallest gains. Each of these participants decreased in either interest or confidence (or both). These girls also showed limited gains in knowledge and creativity, although it should be noted that Gabrielle (and to some extent Allison) was at ceiling for the majority of the knowledge measures at pre test, making it difficult for her to show gains in that area.

4.5 CONCLUSIONS

The methodology described in this chapter represents the author's ideas about quantifying and measuring the development of three habits of mind: the ability to engage in a technological design process, confidence and competencce with respect to technology, and seeing technology as a tool and a creative medium. While these measures captured change in some areas (e.g., robot content knowledge, confidence to engage with robots), little change was detected in others (e.g., robot creativity; interest in technology).

There are several possible explanations for these findings. One explanation is that the seven children involved in this Robot Diaries workshop are not representative of middle school girls as a whole. Rather, this self-selected group was potentially more interested in the topic area (as suggested by comparing their interest ratings with those found for larger samples of middle school students; see Mercier et al., 2006), more motivated, and more experienced with technology at the start of the workshop. This hypothesis is partially supported by a glance at the summary tables, which suggest that some participants were already at ceiling for certain measures before starting the workshop (e.g., Gabrielle for most of the robot content knowledge measures, Chloe for interest measures). In the future, it might be useful to test these measures with larger samples of middle school students to understand where the 'average' student lies.

Such sampling would allow the researcher to evaluate the possibility of showing change with these measures. Also, individual samples could then be measured against this continuum for the purpose of predicting the likelihood of documenting change with these measures.

However, there are also lessons to be learned about the methods themselves. One problematic aspect of the current set of measures was the repetition of pre-post tasks. While several tasks were designed to be isomorphic (e.g., the creative uses task), changes in task structure may have been either too small or too large to allow appropriate pre-post comparisions. Others tasks, such as the design process knowledge task, may have suffered from participants being asked the same set of questions by the same researcher at pre and post interview – participants may simply have chosen not to repeat themselves in this circumstance, leading to lower scores on the post interview.

The current methodology attempted to capture change in a wide variety of areas, including robots, art, design, computers, and everyday technology. However, little change was seen in elements peripheral to the content of the workshop, such as everyday technology. Future Robot Diaries methodology might focus exclusively on robots and technology design. Assessments might also focus on participants' understanding of the *function* of technology and the design process in everyday life, as opposed to declarative knowledge or divergent thinking about the uses of technology.

In conclusion, the current set of measures may have lacked the precision required to capture the range of changes associated with a techology fluency-building experience such as Robot Diaries. Future measurement protocols would benefit from a clearer focus on robots and design, changes in pre-post task structure, and additional data from a larger sample of students. These and other measurement issues are discussed more extensively in Chapter 5.

5.0 DISCUSSION

This dissertation examined an implementation of the Robot Diaries learning environment with a group of home-schooled pre-adolescent and adolescent girls. The primary research goal was to determine whether taking part in Robot Diaries moved the participants towards technological fluency, as indexed by the adoption of three habits of mind: (1) approaching technology as a tool and a creative medium, (2) understanding how to engage in a technology design process, and (3) seeing oneself as competent to engage in acts of technological creativity. A secondary goal for this study was to further develop the concept of 'technological fluency' and to explore the measurement implications of this construct.

This study employed a mixed methods approach to explore the development and expression of technological fluency inside the Robot Diaries workshop. A qualitative analysis revealed that two distinct patterns of engagement are possible within the Robot Diaries community. Students can successfully participate in the workshop while maintaining an engineering focus (characterized by attention to the structure and function of the robot) or an artistic focus (characterized by attention to the robot's representational capacity). The ability to support and sustain multiple levels of participation is a positive and important quality in a workshop designed to increase girls' engagement in technology exploration activities.

Pre-post assessments revealed changes in participants' confidence with respect to robots, but changes in interest, knowledge, and creativity with respect to technology were more limited.

This is partially owing to a ceiling effect on the interest and knowledge assessments – many of the participants were interested and knowledgeable about robots and technology prior to the start of the workshop.

5.1 INTEGRATING MULTIPLE MEASUREMENT APPROACHES

In utilizing workshop data, knowledge and skills assessments, dispositional assessments (e.g., self-ratings of confidence), and creativity measures, this study represented a novel approach to the measurement of technological fluency. The particular approach taken in this study was motivated by several factors. One was the curriculum design of Robot Diaries. As a hybrid of engineering and arts and crafts curricula, Robot Diaries did not lend itself to standard engineering or educational robotics-type assessment tools (e.g., Sullivan, 2008). Additionally, the curricular emphasis on self-expression meant that participants could potentially be learning a new set of skills to support the use of technology in communication activities. These two factors led to an assessment approach that drew heavily on the creativity literature.

What have we learned about measuring fluency from this mixed methods approach? To answer this question, I first synthesize findings from the two analyses (qualitative and pre-post) presented in this study. I then draw conclusions about the unique contributions of each analysis approach.

5.1.1 Dakota

Table 9 summarizes findings from the qualitative and pre-post analyses of Dakota's Robot Diaries participation.

Table 9. Summary of findings for Dakota. Specific tasks contributing to each pre-post conclusion are identified in brackets.

	Qualitative Analysis	Pre-Post Analysis
Engage in Design Process	Dakota is generally planful in her designs and faithful to those plans Dakota routinely engages in the generation and evaluation of design ideas, and is effective at troubleshooting her own ideas Dakota's design choices are motivated by technical and expressive goals	Dakota shows gains in recognizing the presence of computational entities in technology [Design task; Understanding Technological Systems task] Dakota shows slight gains in technology knowledge [Knowledge of Technology Components tasks] Dakota does not show any change in declarative knowledge about the design process [Design Process Knowledge task]
Beliefs About Technology	Dakota has developed creative solutions to meet both technical and expressive goals Dakota uses the robot as a platform for furthering her own interests	Dakota shows a small increase in the number of creative uses generated for familiar and robotic technologies [Creative Uses task] Dakota does not show any change in the number of communication modes imagined for a new technology [Design task] Dakota shows little change in her self-reported interest in robots [Interest survey]
Confidence	Dakota is confident about her abilities as a builder/engineer	Dakota shows increases in confidence with robots and other technologies [Confidence survey]

5.1.1.1 Engage in a Design Process.

Results from the qualitative analysis suggest that Dakota was able to successfully engage in a design process. She planned out her designs and remained faithful to those plans, was able to evaluate and troubleshoot her design ideas, and could design towards both technical and expressive goals. From the pre-post quantitative analysis, we learn that Dakota continued to develop technical knowledge over the course of the workshop. To be more specific, Dakota's performance on the design task and on multiple technology content knowledge measures indicate that the workshop helped Dakota recognize the importance of computational entities as control mechanisms in technology.

5.1.1.2 Beliefs About Technology.

The qualitative analysis suggests that Dakota sees technology as a flexible and creative tool. During the workshop, she demonstrates that she is able to be creative with robotic technology in technical and expressive ways. Additionally, this analysis suggests that Dakota has begun to use the robot as a platform for furthering her own interests. These conclusions contradict those drawn from the pre-post assessments, which suggest that Dakota has not become any more creative in her thinking about technology, nor has her level of interest changed.

5.1.1.3 Confidence.

The qualitative analysis suggests that Dakota was fairly confident in her ability to design and build her robot during the workshop. The pre-post survey suggests a similar conclusion – Dakota's level of confidence was moderately high at the start of the workshop, and only increased as the workshop progressed.

5.1.2 Allison

Table 10 summarizes findings from the qualitative and pre-post analyses of Allison's Robot Diaries participation.

Table 10. Summary of findings for Allison. Specific tasks contributing to each pre-post conclusion are identified in brackets.

	Qualitative Analysis	Pre-Post Analysis
Engage in Design Process	Allison's design plans are not strict guides for her robot building activities Allison generates a lot of ideas, but often relies on others to evaluate the technical feasibility of those ideas Allison's design choices are primarily motivated by expressive goals	Allison recognizes the need for computational entities at pre-test in a system she models, but does not include computational entities in her descriptions of existing systems at pre or post test [Design task; Understanding Technological Systems task] Allison simplifies her design when modeling a novel technology system [Design task] Allison shows few gains in her overall knowledge of technology components [Knowledge of Technology Components tasks] Allison does not show any change in declarative knowledge about the design process [Design Process Knowledge task]
Beliefs About Technology	Allison has developed creative solutions to meet her expressive goals Allison sees her robot as a representation	Allison shows a decrease in the number of creative uses generated for familiar and robotic technology [Creative Uses task] Allison shows an increase in the number of communication modes imagined for a new technology [Design task] Allison shows a decrease in her self-reported interest in robots [Interest survey]
Confidence	Allison is hot and cold in her confidence with the technical elements of robot building	Allison shows an increase in her self-reported confidence with robots and computers [Confidence survey]

5.1.2.1 Engage in a Design Process.

The qualitative analysis suggests that Allison had difficulty executing some steps in the design process. Specifically, she needed help in evaluating and troubleshooting her design solutions. However, she was able to design somewhat effectively towards expressive goals. The pre-post tasks suggest that Allison began the workshop with a moderate amount of technical knowledge, and that her knowledge did not really change as a result of participating in the workshop. At post test, her understanding of the need for computational entities in complex technologies was still incomplete (she included computational entities in a system she modeled, but did not include them in her descriptions of pre-existing systems). However, the decrease in complexity in her design task solution suggests that she may be starting to understand how complex technical systems function.

5.1.2.2 Beliefs About Technology.

The qualitative analysis suggests that Allison sees technology as a flexible tool for self-expression. This is evident both through her creative solution for meeting an expressive goal, and her persistence in seeing her robot as a representation (of herself and of the character Lily). The pre-post analysis does not paint a clear picture of changes in Allison's beliefs about technology. She generates fewer solutions for novel technology uses in a divergent thinking task (the 'creative uses' task) at post test, but more solutions for communication possibilities in the design task.

5.1.2.3 Confidence.

The qualitative analysis suggests that Allison is gaining confidence in her ability to engage with complex technologies (like robots), but that she still has some doubts about her abilities in this area. The pre-post confidence survey suggests that Allison's self-reported confidence to engage with robots and computers increased after the workshop.

5.1.3 Synthesis

5.1.3.1 Engage in a Design Process.

Each analysis approach provided different information about the participants' ability to engage in design. The qualitative analysis provided details about how each participant executed the steps in the design process, while the pre-post analysis assessed each participant's knowledge about the components utilized in technology design and the function of technology systems. Arguably, these are complimentary categories of information – a designer's level of knowledge has been shown to be relevant to his or her participation in the design process (Chevalier & Ivory, 2003; Fricke, 1996). The findings reported here somewhat support conclusions about the relationship between knowledge and design participation – Dakota, who showed a fairly complete understanding of the technology by the end of the workshop, successfully executed the steps in the design process. Allison, whose knowledge was less complete, had difficulty executing certain design steps.

It is possible to imagine a pre-post task that assesses a participants' ability to engage in the design process. The design task used in this study attempted to do so, but only had the students building models of new technologies. In order to really gauge participants' ability to evaluate and implement different design ideas, participants would need to build working technology artifacts. Tasks like this do exist in the realm of robotics education (e.g., Sullivan, 2008). Such tasks may be appropriate for evaluating fluency in a Robot Diaries-type context if they are adapted to allow for the completion of more fluid, creative, or participant-led goals.

5.1.3.2 Beliefs About Technology.

The two analysis approaches yielded different, and at times contradictory evidence regarding participants' beliefs about technology. The qualitative analysis captured the range of beliefs represented by the girls' artifacts, while the pre-post assessments captured their responses to a set of fictional, technology-based situations.

It is difficult to imagine a pre-post task that can assess a range of beliefs like those encapsulated in the artifacts themselves. Perhaps this is because the act of creating technology to communicate one's own message is necessarily a personal act. Unlike other robotics experiences where students are building a robot to fit external specifications, Robot Diaries participants worked towards the goal of infusing their artifacts with their personal beliefs and preferences. By and large this type of adaptation would be difficult to assess with a standard instrument. Rather, the assessment would need to be based upon the artifacts themselves, perhaps with a set of metrics to guide assessment activities. One model for doing this type of assessment is the Consensual Assessment Technique (Amabile, 1996; Hennessey, 1994). Using this method, independent raters are asked to judge artifacts on a pre-determined set of metrics, such as creativity or technical goodness. While the ratings provided using this method are subjective, independent raters have been shown to produce reliable rankings (Amabile).

Student self-reports of interest and motivation to continue these types of activities should be assessable via interview or survey instruments. The particular interest measures used in this study were adapted from surveys created for a general population (Mercier, Barron & O'Connor, 2006). These types of instruments could be re-designed to reflect the opportunities available in a learning environment like Robot Diaries. Such a re-design might focus on questions about student interest in personalizing technology or adapting it for their own use (e.g., 'it is important to me to know how to adapt technology so I can use it the way I want to').

5.1.3.3 Confidence.

Based upon the findings presented in this study, a self-report confidence measure seems appropriate for assessing changes in student confidence to design and build robots.

5.2 DEFINING AND MEASURING MULTIPLE PATHWAYS

Assessing the development of technological fluency is challenging. I believe that the crux of this challenge is the existence of multiple pathways to fluency. This study identified two such pathways (engineer and artist) available to participants in Robot Diaries. Existing measurement tools tend to focus on one pathway (frequently engineering). Developing measurement tools that can accommodate multiple pathways into fluency will be a difficult next step.

This chapter has summarized the current efforts towards measurement and drawn conclusions about how we might develop tools to facilitate our efforts in this area. Quantitative measurements for fluency development are possible, but seem unlikely to capture the entirety of the shift towards fluency, particularly with respect to students' attitudes about technology. Further research is needed to determine the best ways (qualitative or quantitative) to measure this part of the construct.

The idea of multiple pathways encompasses an unspoken trade-off – an approach with a singular focus (e.g., engineering) could possibly produce higher knowledge gains in the area of focus than an inter-disciplinary program. However, a blended approach may yield other long-term benefits. For example, to individuals who assume that going beyond consumer engagement with technology requires a high level of interest in engineering and/or computer science, providing alternative methods of engagement sends the message that technology is accessible and (perhaps) more flexible than they initially thought. This is a useful attitude to forward, particularly if our goal is to increase the number of citizens capable of innovating with technology. There is also a global benefit to encouraging students to develop multiple ways of being creative with technology. As the NRC (1999) rightly points out, frequent changes in 'state of the art' technology require us to be capable of adapting our knowledge and skills. But we also need to be creative and flexible in how we utilize our technological tools. Hybrid approaches to technology outreach may help provide the broad base of creative individuals needed to make the most of available technology.

5.3 THE ROLE OF KNOWLEDGE

One additional question deserves consideration here – what is the role of knowledge in technological fluency? Is the move towards technological fluency akin to creating 'experts' in technological domains? Or, is there particular knowledge that is required for fluent technology engagement?

One way to address this question is to think about the impact of knowledge on the processes implicated in fluent technology engagement. Participation in a design process, for example, is directly impacted by the extent of a designer's knowledge. A recent review of the design literature suggests that an individual's depth of knowledge can impact the way they engage in design, for example by helping them infer design constraints (Bernstein, 2007).

However, the link between knowledge and other aspects of fluent technology engagement is less clear. Consider, for example, the relationship between knowledge and attitudes about technology. Exposure to a variety of different technology uses seems as thought it may positively impact attitudes about technology, but this relationship would be best understood with additional empirical work.

There is also another perspective to consider – while we may assume that some level of relevant knowledge is required to engage in technology design and adaptation, it may not be the case that the knowledge needs to reside within one individual. Some researchers (e.g., NRC, 2006; see also Jenkins, 2006) have suggested that technological literacy or fluency can be considered a distributed resource, with the relevant knowledge and skills shared by a group. As social media continues to encourage and enable the sharing of ideas and projects, this point of view becomes more relevant and practical.

5.4 CONCLUSION

This study has examined the development of technological fluency in a learning environment that encouraged students to explore and integrate technology and communication, and adapt their knowledge to suit their own ideas. The major contributions of this study are the indexing of technological fluency via three habits of mind, and the development of measurement tools around these habits of mind.

Results suggest that the Robot Diaries learning environment enables multiple patterns of engagement – participants can engage as artists or engineers – as well as consistent pre-post gains in certain areas (e.g., confidence in designing and building robots).

This study has implications for the design of learning environments to support fluency development and also measurement tools for technological fluency. Qualitative and quantitative approaches to measurement provide different but complimentary information about fluency development. Further research is needed to explore the best way to measure students' attitudes towards technology.

APPENDIX A

CHILD PRE/POST INTERVIEW QUESTIONS

Part 1: Prior Experience (Pre-test only)
To begin, can you tell me a little bit about yourself? What types of things do you like to do?

What are your favorite things to do?

What kinds of things are you interested in learning about?

What kinds of projects do you like to do (for example, projects where you've decided to make something?)

- Tell me a little about what you did.
- How did you get started on this project?
- Why did you do it?
- How did you do it?
- Were there things you needed to learn in order to finish your project? If so, what? how did you learn them?
- What challenges did you have working on this project? Did you ever get stuck on something? If so, what did you do?
- Were there things you needed help with on this project? If so, how did you obtain that help?
- How long ago was that?

Can you tell me why you decided to participate in Arts and Bots?

What do you think is going to be your favorite part of Arts and Bots?

What are you most looking forward to learning in Arts and Bots?

Part 2: Knowledge Related to the Design Process
On a scale of 1 to 5, where 1 was someone who never uses technology and 5 was someone who uses it a lot, where would you put yourself? [show scale] What types of technologies do you use?

[pick one technology child mentions]

- Can you tell me a little bit about that technology?
- What do you do with it?
- What do you think is inside it (what parts are inside it)?
- How does it work?
- What would you do if you were using it, and it stopped working? (or if you couldn't get it to work?)
- Tell me a little bit about how you think this technology was invented.
- PROMPT: Once someone decided, okay we're going to make a _____, what did they need to do next?
- How did they know it would work?
- What if they made it and it didn't work? What would they do then?

Part 3: Ideas about technology
I want to show you a video, of a piece of technology that I think you might like. [show video: Birds Leap to Fly]

- Talk to me a little bit about what you saw in the video. What was happening?
- Do you think it's interesting? Why or why not?
- How do you think this technology works? What parts are inside?
- Why do you think the creator made this?
- If you could ask the creator anything you wanted to about this technology, what would you ask him?
- Sometimes technology can be expressive. Do you think the creator is trying to say something or express something with this technology? What are they trying to say?
- Do you think this is a robot? Why or why not?

Now we're going to talk about some technologies that might be familiar to you. I want you to think about how you normally would use them, and then I want you to think about some different ways you could use them.

- Cell phone
- iPod
- electric mixer (like in your kitchen)

Part 4: Knowledge questions
I'm going to show you a bag of things (a sensor, a servo, a switch, battery pack, LED, alligator clips).

- Have you seen any of these things before? Do you know what they are? If not, take a look – what do you think they do?

[Identify sensor, if child has not already] Can you tell me what you know about sensors?

- o [Probe for a definition; if child says 'it senses things', ask what it can sense]
- o Can you give me an example of something that uses a sensor?
- o How do you think a sensor works?

[Identify electric motor, if child has not already] Can you tell me what you know about electric motors?

- o Can you give me an example of something that uses an electric motor?
- o How do you think an electric motor works?

(SHOW IDOG) Introduce the toy (let them use it for a minute).

- Have you ever seen a toy like this?
- What do you think it is, or does?
- How do you think it works?
- What's inside?
- Do you think the iDog can learn?
    - o [If no or I don't know] how could you find out if it could?
    - o [if yes] How do you think it learns? How could you tell if it had learned?
- Does the iDog know what you're doing? If so, how?
- Do you think you could take it apart? How?

Part 5: Card Game [with pre-test scenarios]
Now we're going to play a game where I'm going to ask you to think about some situations and how you might use different types of technology in those situations.

Situation #1: You have noticed that someone has been coming in to your bedroom when you are not there, and is looking through your stuff. How could you use technology to help protect your privacy?

Situation #2: Someone you know (and care about) has started smoking. How could you use technology to help them quit?

Technologies: cell phone, digital camera, something you build which can have motors/speakers/sensors/lights

Questions for each round:

- Great idea. So how would that work? Can you tell me more about how it would work?
- Now, if you were going to make that, what steps would you take?
- What would be the most challenging part about building this?
- Do you think you could do/build something like this?

Part 6: Design and Modeling Task [with pre-test scenario]
Recently, you and your neighbors have noticed that there are a number of loud cars driving up and down your street, making the block very noisy.

Knowing that you are interested in technology, the neighborhood association has hired you to develop a new technology that will help make the street quieter.

They have asked you to build a model. A model can show what something will look like and how it will work once it is built. You will use these materials (show materials) to make your model.

In order to build your technology, they have given you the following parts:
- a sensor (to sense the environment)
- a speaker
- 2 lights
- 2 motors

What I'd like you to do now is imagine a technology that used those parts, and build a model of it using the craft materials. There is paper and a pencil here, so you can draw if you want to. While you're building, I'd like to know what you are thinking about, so try to talk out loud as you are building.

[probe every 3 minutes]

Questions to ask after design:
- Can you tell me about what your model? How does it work?
- Do you think this will do a good job reducing the amount of noise on your street? (please explain your answer)
- Let's talk about what would happen if someone wanted to take your model and built the technology that you have suggested/modeled.
    - How would they do it? What steps would they go through?
    - What materials or parts would they need?
    - Do you think it is likely that this machine would work/run [would it really do ____], or do you think it would not work? Why/not? What would be hard/easy about it?
    - How could they test it (to make sure it was working)?
    - What challenges would they face in building this?
- How could you change your design to make it even more effective at reducing the noise on the street?

APPENDIX B

CHILD POST-ONLY QUESTIONS

Questions about the Play

- What was your favorite part of your play?
- What part of your play are you most proud of?
- Why did you choose to base your play on that story?
- Did you enjoy working on the play? Why or why not?
- What was your job in preparing for the play? What was everyone else's job? How did your group work? Who was in charge of your group?
- Did you have a script?
- What was the hardest part of preparing for the play?
- Is there anything that you wished you could have done differently in the play?
- How much time did you spend working on the play out of class?
- What did you spend that time doing?
- Have you ever put on plays before? How was this similar/different?
- What did you think about the other play?

Sample questions about the Robot (many of these questions were tailored for each child)

- Is this a robot? What makes it a robot?
  - What's your definition of a robot?
- What is the most unique thing about your robot?
- Of all the programs you've written, which are you most impressed with? Why?
- How does your robot work?
  - How does it move?
  - How do the programs get from the computer to the robot's motors and lights?
- Let's talk about the process of building your robot.
  - Last time we spoke, you said that before the workshop you were thinking of building a lizard robot that could climb walls. I was wondering where that idea came from.
  - *[Show picture of her robot from the first robot design session].* This is a picture of your robot from the first day of robot building. How did you get from there to here? Where did your ideas come from?
    - Sketch from 10/9/08 – can you tell me what's here
    - Were the feet part of your original plan?

        - Sketch from 10/16 – can you tell me what's going on here? Why move eyes lower? Ears here?
        - Sketch from 10/23 – booster box?
        - Can you tell me about rebuilding the head? What did you do and why?
        - Did you need to rebuild anything else on your robot?
    - Did you get feedback from people about your robot? Like people you showed the robot to outside of class?
        - Did you use any of that feedback to make changes to your robot?
    - Did you encounter any problems during building?
    - Can you tell me about some of the things that haven't worked, like things you tried to do but they didn't work?
    - Are there things you thought about adding but didn't?
        - Tongue?
- Where has your robot been living at home?
- Tell me how you program your expressions.
    - What do you think about/do?
    - How do you decide what elements to use?
    - Which are the most important parts of your robot for expression?
- Did you do any robot building at home?
    - If so, how? Did you need to bring parts home with you? Did anyone help you?

Questions about the workshop

- What is the thing you enjoyed most about the workshop?
- What has been your least favorite thing about the workshop?
- What has been the hardest part of the workshop?/hardest thing to do?
- What is the thing you are most proud of?
- What did you felt most/least confident doing in the workshop?
    - How did you feel about designing your own robot?
    - What about programming your robot – easier or harder than you thought?
    - Actually building the robot – easier or harder than you thought it would be?
- Was there any point during the last few weeks of the workshop that you needed help doing anything at home?
- Outside of your workshop friends and instructors, have you talked to anyone about this workshop? If so, who? What did you talk about?
- How would you describe this workshop to another girl your age? Would you recommend this workshop to another girl your age? Why or why not?
- If there were a robotics workshop offered through [homeschool enrichment program] next year, would you sign up for it?

APPENDIX C

PARENT PRE-INTERVIEW QUESTIONS

Can you tell me why your daughter decided to sign up for Arts and Bots?

Did you encourage her to sign up?

What types of activities does your family like to do together?

Do any of those activities involve technology? Please elaborate.

Do any of those activities involve art or arts and crafts? Please elaborate.

Next, I wanted to get a sense of your daughter's interests. What kinds of activities is your daughter currently involved in (i.e. sports, clubs, etc.)? What does she like to do?

I wanted to get a sense for your family's level of interest in technology in general, and robotics in particular. Would you say that your family is interested in technology in general? (do you talk about it?)

Has your daughter ever participated in any activities that focused on technology, engineering, or robotics?

If so, what activities did she participate in?

Why do you think she chose to participate?

When did she participate in these activities?

What do you think she got out of participating in this activity? What do you think she learned?

How would you describe your daughter's overall attitude towards technology?

- Is she comfortable using new or unfamiliar technologies? What are the technology items that your daughter uses most?
- Is she generally interested in it (if so, what is the nature of this interest? How does she use technology?).
- Would you say she is curious about technology or the way things work?

- Are there any particular technologies that she's expressed an interest in? if so, has anyone ever followed up with her on these interests?
- Has she ever taken something apart to see how it works? has anyone in the house ever explored technology with her in this way? If so, can you give an example? Who initiated the situation?

Do you think she knows anything/a lot about technology (like how it works)? Please explain. What do you think she knows most about? What are the limits of her knowledge?

Let's talk about the technological or gadget-y items in your house – do you have a lot of technology or gadgets in your house? If so, what? Who uses them? Has your daughter expressed interest in these items?

How about you? Would is your attitude towards technology? Would you describe yourself as someone who is interested in technology, or knowledgeable? Is your spouse? If yes, is you or your spouse's interest work-based, a hobby, or is it just an item of general interest?

Has anyone in your house ever built a piece of technology (or a robot)? If so, who? Has your daughter ever done so?

Of all the members of your household, who would you say is most likely to do something creative or different with technology? Who is least likely? Why?

Now let's talk about more expressive activities or hobbies, like arts and crafts, music, writing. Are these activities that members of your family are interested in? Has your daughter ever expressed interest in these types of activities? If so, how would you describe her interest?

Has your daughter ever participated in any activities that focused on art or arts and crafts?

  If so, what activities did she participate in?
  Why do you think she chose to participate?
  When did she participate in these activities?
  What do you think she got out of participating in this activity? What do you think she learned?

When your daughter wants to know more about something, where does she usually turn for information?

  Specifically, if she wants to learn more about a technology, or has a question about how something works, where would she get her information?
  What about for other information? If she was working on a project (e.g., an art project), where would she turn if she had questions about something?

Does your daughter share her knowledge about technology with anyone in the house? For example, has she ever helped you or another family member (e.g., a sibling) with technology, or taught someone else what she knows about it?

Has she ever done this with art or arts and crafts?

Has your daughter ever seen or used a robot? If so, please explain the circumstances. What did she do? What do you think she got out of it?

Do you think she knows anything/a lot about robots? Please explain. What do you think she knows most about? What are the limits of her knowledge?

Has your daughter ever used technology in a way that surprised you? For example, has there ever been a time when your daughter used or did something with a piece of technology in way that was different than its original intended use?

How often (hours/week) does your daughter use the computer? Does she have a computer in her room? If not, where is the computer located that she uses the most? Does your daughter use the internet? What does she use the internet or computer for?

How easy or hard do you think it would be for your daughter to enter into a technology career?

How long have you been home schooling? Why did you decide to home school?

APPENDIX D

PARENT POST-INTERVIEW QUESTIONS

I'd like to begin by once again thanking you for your participation in Arts and Bots. We've really enjoyed working with you and your daughter on this project.

The purpose of this interview is to collect your observations and reflections about the project. Let me start by asking you, once again, to reflect on your daughter's participation in this project. What are your overall impressions about the workshop?

During our last interview, we talked about what you were hoping your daughters would 'get out of' the workshop. Can you remind me what those things were. Do you think that she has gotten those things from the workshop, or not? Are there other things you were hoping she might take away from the workshop that she has not?

Were you disappointed in any aspects of the program? For example, are there specific things you had hoped she would learn or gain that she has not?

Have you been surprised by anything your daughter has said or done with respect to this workshop?

Outside of what your daughter specifically may have experienced, have you noticed any household-wide changes as a result of her participation in the workshop? [Probe: for example, any changes to family activities, changes to the family's general level of interest in technology?]

I wanted to ask a few questions about the home-based activities associated with this project.

- What has she mostly been doing at home with the robot?
- Has your daughter ever asked for help while working with the robot at home or doing homework? (who did she ask?)
- Have you and your daughter talked about the workshop? If so, what did you talk about? Did you initiate or did she? Has she talked to anyone else in the family about it? Do you know what they talked about?

- Has your daughter been sharing the robot with anyone else/letting anyone else use it with her or without her (sibling, friends, etc.)?

What do you think of your daughter's robot?

- What do you think is the most interesting part of her robot?
- Were you surprised by the particular robot she built? Why or why not?

What did you think of the plays?

- Which were the most interesting parts of the play?

During our first interview, I asked you a number of questions about your daughter's attitude towards technology, her interest in technology, and her knowledge. What I'd like to do now is to discuss those same topics again, and ask you if you have seen any changes in any of these areas. It goes without saying that it's fine if the answer is 'no' to these questions…

- Have you noticed any changes in how she uses technology items?
    - For example, any changes in her level of comfort using technology?
    - Particularly, new/unfamiliar technologies?
    - Have you noticed any changes in the technology items that your daughter uses most?

- Have you noticed any changes in her general level of interest in technology (if so, what)?
    - For example, are there particular technologies that she has expressed an interest in lately that she hadn't been interested in before?
    - Any changes in her level of curiosity about how things work?

- Have you noticed any changes in her overall attitude towards technology?

- Have you noticed any changes in your daughter's level of knowledge about technology?

- Have you noticed any changes in your daughter's interest or knowledge about arts and crafts?

- Have you noticed any changes in your daughter's sharing her knowledge about technology with others in the house? Any changes in frequency/willingness to do so?

Have you noticed any changes in your daughter as a result of her participation (that you haven't already mentioned)?

Over the past 6-7 weeks (the course of the workshop), has anyone in the house explored technology items with your daughter (e.g., taken something apart, or an in-depth conversation about how something works)?

Has your daughter ever used technology in a way that surprised you? For example, has there ever been a time when your daughter used or did something with a piece of technology in way that was different than its original intended use? If yes, when did this take place?

How easy or hard do you think it would be for your daughter to enter into a technology career?

In general, if you could change anything about Arts and Bots to make it a better experience for middle school girls, what (if anything) would you change?

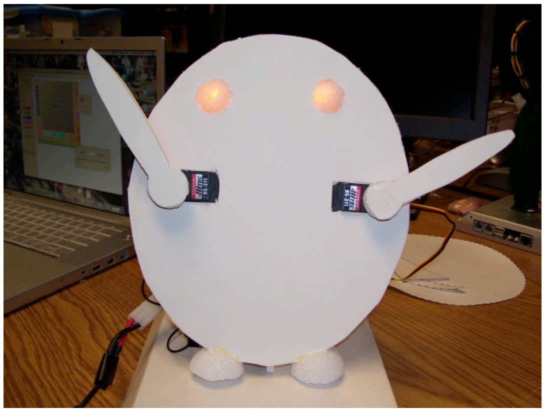
Do you think you will encourage your daughter to continue exploring robotics or technology, or is that not something you would encourage her to do?

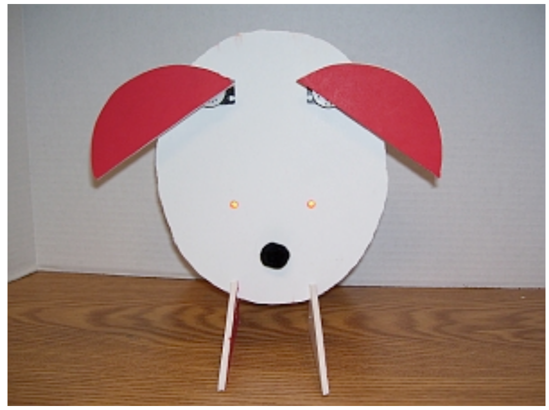
- If yes, are there specific steps you plan to take to encourage this exploration?
- Would you encourage her to take more robotics/technology classes in the future? Why/not?

Is there anything else related to Arts and Bots that you would like to share with us?

APPENDIX E

HANDOUT FROM FIRST ROBOT DESIGN SESSION

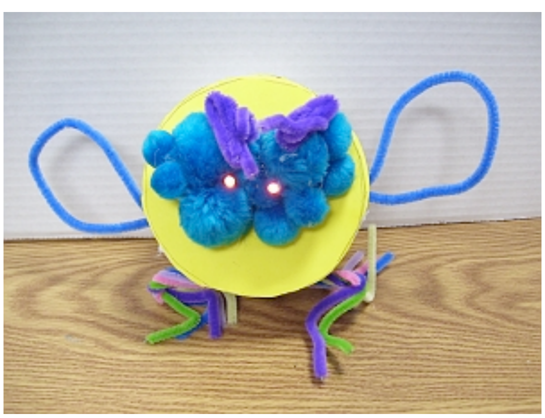


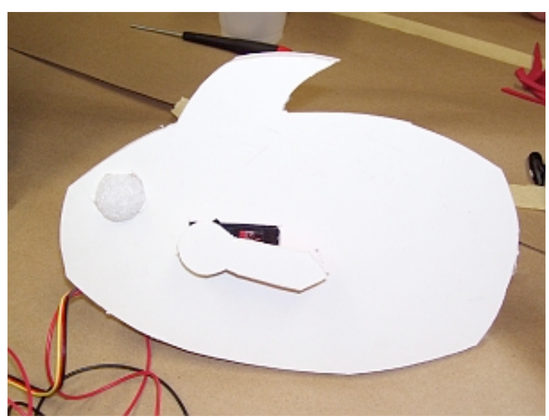


Today you are going to build an expressive robot that has a body, 2 servos, and 2 LEDs. The servos can control arms, legs, ears, antennae, wings, fins, heads, tails, and so on. The LEDs can be used in the eyes, ears, nose, antennae, or some other part of your robot.

How will your robot look?

Before you begin building you need a plan. Draw one or more pictures of your robot. Label the moving parts and the LEDs.





APPENDIX F

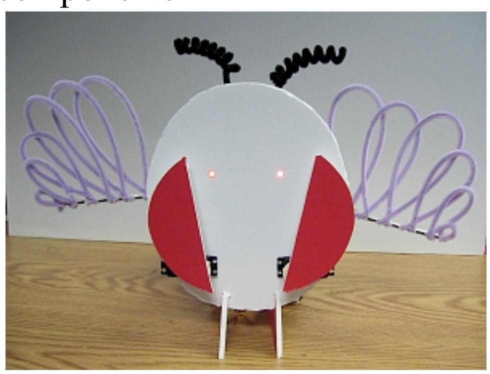
HANDOUT FROM SECOND ROBOT DESIGN SESSION

Today, you can make your robot more expressive by adding additional servos, LEDs, motors and sound capabilities. You will have at least 3 sessions to work on your additions and robot customization so you can test your robot between sessions and make improvements at the next session.

The additional components you can use are:

- 2 additional servos
- 4 additional LEDs
- 2 vibration motors
- 1 motor
- 1 speaker

Try to integrate as many components as you can. By the end of the final design session, you should have used at least 3 of the 5 different types of components listed.



For today, try to integrate at least one new component into your robot.

Adding these additional components will require you to re-design parts of your robot. This is all part of the design process. Now you have a chance to improve your robot and make it exactly the way you want it!

Before you begin building spend 20 minutes brainstorming about how you will add new components to your robot to make it more expressive. Draw some sketches in your notebook and label the new components.

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