Electronic Blocks: Tangible Programming Elements for Preschoolers

Peta Wyeth[1,2] & Gordon Wyeth[1]

[1]Computer Science and Electrical Engineering
[2]CRC for Enterprise Distributed Systems Technology
University of Queensland, Brisbane, Australia

pwyeth@dstc.edu.au
wyeth@csee.uq.edu.au

Abstract: This paper describes the design, implementation and evaluation of Electronic Blocks, blocks with electronic circuits inside them. By placing Electronic Blocks on top of one another young children build "computer programs" – each stack of Electronic Blocks is capable of a different function. Significantly, the blocks programming input and program output are based in the physical world, with the digital implementation completely hidden from the children. Preliminary studies have found that children aged between four and six are capable of using the blocks to create robots that crash into each other, remote control cars, and lights that flash when you clap. Most children became heavily engaged with the blocks, and learnt simple programming with a minimum of adult support.

Keywords: education, programming, children, tangible interface

1 Introduction

Electronic Blocks are tangible programming elements that can be physically stacked and arranged to form computer programs that interact with the physical world. The Electronic Blocks have been designed to provide young children, aged between three and eight years of age, with opportunities to explore technology in a purposeful and appropriate way.

Undeniably, technology education for children is becoming increasingly important. In the specialist area of early childhood education there is a continuing challenge for educators to develop educational programs that recognise and respond to the impact of the 'information revolution'. It is especially important for young children, as they explore and make sense of the world around them, to have positive experiences with computers and technology.

However within the field of early childhood, the issue of integrating computers into the curriculum has been debated for the past 20 years. Concerns about young children's physical and cognitive readiness to use computers and the impact of computer use upon their social and educational development has led to a reluctance on the part of many teachers and school administrators to view computers as an appropriate early childhood educational resource (Bailey & Weippert, 1991).

At issue is that young children learn best while actively manipulating and transforming real materials (Beaty, 1984), as is dictated by their sensory dependence. Therefore, educators argue, it is important that experiences with technology are empowered accordingly. Young children need to be able to play an active role in their encounters with technology, and in doing so develop images of machines and computers that they can control and program (Resnick, 1993). As a consequence of such interactions, young children will develop new images of themselves as young people who can have an impact on technology.

Electronic Blocks address this issue. Unlike the computer and many other media used for technology education, both the input and the output to the Electronic Blocks are physical, making them perfectly suited to sensory-dependent children.

Of the interactive programming environments developed for use by young children (Papert, 1980; Kahn 1996; Smith et al, 1996; Resnick, 1993), *curlybot* (Frei et al, 2000) is perhaps the only other resource in this category. All seek to enable children to use the dynamic and programmable properties of the computer, with the aim of enhancing cognitive skills.

There are a number of advocates that support this viewpoint. Papert (1980), in his landmark work Mindstorms recognised that computer programming as an educational activity had great potential as a vehicle for the acquisition of useful cognitive skills such as problem solving and reflective thinking. Sheingold (1987) proposed that the power of the computer in pre-school settings lay in its ability to acquaint children with the dynamic and programmable properties unique to it. Research carried out at the MIT Media Laboratory for the last decade has extended this theory. Resnick et al. (1996) assert that the empowering properties of computer programming, with its ability to enable users to become creators, not just consumers, of computing activities, provide positive outcomes for learner.

Electronic Blocks represent a paradigm shift, away from using the computer to teach programming, towards a physically embodied system that provides programming experiences that involve active manipulation of real materials. This programming interface has been designed to take into account the special needs of children under eight and has been based on early childhood development and learning research.

2 Design Goals

The design of the Electronic Blocks is based on the belief that one of the best ways to gain a deep understanding of something is to create it. The Electronic Blocks, therefore, have been designed to encourage unstructured exploratory learning that allows children to construct programmable artefacts and observe the resultant dynamic behaviours.

The development of the Electronic Blocks has been guided by two design goals:

1. To produce a developmentally appropriate resource for early childhood technology education (based on Bredekamp and Copple, 1997); and
2. To create a resource that has the dynamic programmable properties of a computer, minus its complexity.

The first design goal is focused on introducing technology to young children in a developmentally appropriate way. Young children know how to play with physical objects – this is how they explore and make sense of their world. Manipulation of symbolic systems (the way adults make sense of the world) is generally considered to be beyond the capabilities of most young children. Electronic Blocks are designed to allow children to be active participants in design and construction activities in a domain that is accessible to them – playing with physical objects.

The second design goal focuses on the creation of a resource that has the unique dynamic and programmable properties of a computer minus its complexity. Electronic Blocks are designed to allow children to be active participants in programming activities, ensuring concrete interactions are the primary means by which children explore the dynamic programmable properties of the blocks.

Young children who are not yet able to read or write should be able to explore new concepts of programming and control (based on Resnick, 1987) by manipulating and transforming real materials.

3 Electronic Blocks

The Electronic Blocks have been designed so children can connect them just as they would any other blocks. The blocks have been made by placing electronics inside Lego Duplo Primo™ blocks. This ensures that the blocks are easy to stack and connect. The blocks have inputs and outputs and when connected, the output of one block controls the input of another. There are three kinds of Electronic Blocks: *sensor* blocks, *action* blocks and *logic* blocks.

Figure 1: The complete Electronic Block family: the three sensor blocks are to the left (*seeing* at the front, *touch* in the middle and *hearing* at the rear), the four logic blocks are in the centre (*toggle* at the front, *not* in the middle and *delay* at the rear next to the double *and* block), and the action blocks to the right (*sound* at the front, with the *light* and *movement* at the back).

3.1 Sensor Blocks

There are three sensor Electronic Blocks: a *seeing* block, a *hearing* block and a *touch* block. These blocks are capable of detecting light, sound and touch, respectively. They are single connector blocks that have an input from the block above and an output to the block below (see Figure 2). The input from the block above is off if there is no block above or the block above is not sending a signal. The input and the sensor are logically ORed together to produce the output. As a result when two or more sensor blocks are stacked on an action block any sensor input will trigger the block below.

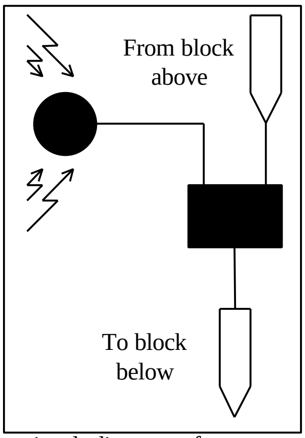

Figure 2: Functional diagram of a sensor block. Either sensory input or an active signal from the block above will cause the output to be active.

All sensor blocks are yellow. This makes the important sensor functionality easy to locate for block stack builders. The different functions of the sensing blocks are identified by readily understandable icons: for example, an eye for a *seeing* block.

3.2 Action Blocks

Action blocks produce some kind of physical output. The l*ight* block lights a bright incandescent bulb, the *sound* block plays a simple children's melody, and the *movement* block is a four wheel car that drives in a straight line.

All action blocks have two inputs from the blocks above. If either input is triggered the block will act. They are physically constrained by a base plate so that they cannot be placed on top of another block and have to be positioned at the bottom of a block stack. Figure 3 shows a *light* block under a *touch* block. The functionality of the action blocks is somewhat self-evident from the physical structure of the blocks. The sound and light blocks are also adorned with explanatory icons.

Figure 3: A touch block attached to a light block will cause the light to turn on whenever sensor plate is touched.

3.3 Logic Blocks

Logic blocks have an intermediary role. Placed between a sensor block and an action block they have the ability to alter the expected action. Logic blocks provide users with the capability to:

?? produce an action if a particular stimulus is not received (*not*),

?? toggle the input so that in the first instance the stimulus from the environment will "turn the action on" and the second instance of the stimulus will "turn the action off" (*toggle*),

?? stretch a short signal so that the action will stay on for two seconds after the stimulus stops (*delay*), and

?? only produce an action if input signals are received simultaneously through both inputs (*and*).

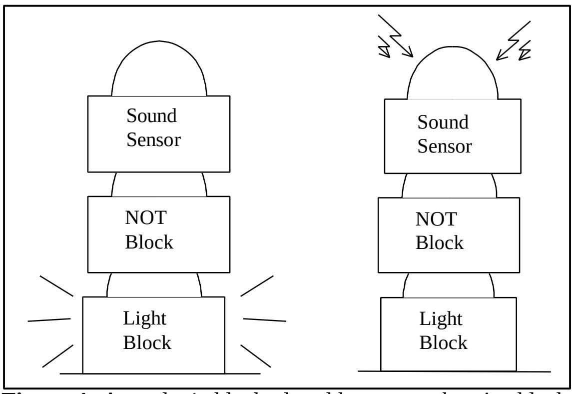

Figure 4: A *not* logic block placed between a *hearing* block and a *light* block performs a logical NOT operation causing the light to go on whenever there is *no* sound.

With the exception of the *and* block, these blocks are single connector blocks with an input attached to the upper connector and an output attached to the lower connector (see Figure 4). The input of the blocks is off when no block is connected to the input. The *and* block, a double connector block, has two upper connectors which may receive an input signal. The block works as a logical AND – it must receive an input from both connectors to produce an output. The output signal produced is attached to both lower connectors.

Each different logic block type has distinctive icons and colours to assist their identification. It is difficult to choose meaningful icons for these blocks. What icon explains “and” to a preschooler? The icons were chosen to have readily understood adult meanings: for example, & for “and”.

4 Preschoolers Programming with Electronic Blocks

The Electronic Blocks are designed so that by simply playing with the blocks, children can produce interesting behaviours that they find fascinating. They might build a block tower that flashes when they talk, or moves with their touch. These are examples of simple sensor-action combinations. Given a set of three sensor blocks and three action blocks, there are a total of nine such combinations.

The addition of logic blocks to the set of Electronic Blocks opens up a wide variety of additional construction opportunities. A task that sees the introduction of a logic block is the creation of a car that starts when you clap and stops when you clap again. A *toggle* block placed between a *hearing* block and a *movement* block will achieve this result. Logic blocks add to the complexity and variety of structures that may be created.

Figure 5: A remote control car demonstrates interaction between block stacks. The *touch* block on the *light* block forms the remote control for the car formed by placing a *seeing* block on a *movement* block.

A fascinating aspect of Electronic Blocks is their ability to interact not only with the environment but also with each other. An example of two Electronic Block structures interacting is the creation of a remote control car. By creating one block stack which contains a *touch* block and a *light* block and another stack which has a *seeing* block on top of a *movement* block, a child has effectively created a remote control car. By pressing the *touch* block, the child triggers the light. This light in turn is detected as an input by the *seeing* block which actives the *movement* block (see Figure 5).

5 Evaluation of Electronic Blocks

Each of the design goals translates to a research question. In order to assess the level to which the Electronic Blocks have met the design goals, the following the questions must be explored:

1. Are Electronic Blocks a developmentally appropriate resource for early childhood technology education?
2. Are children able to access the dynamic programmable properties of the Electronic Blocks?

Research question 1, focuses the evaluation on determining whether the children can use the Electronic Blocks easily, whether they enjoy using the Electronic Blocks and whether they understand what they were doing with the blocks.

To explore these issues, the evaluation must investigate the participants’:

?? Levels of enjoyment
?? Levels of attention and interest
?? Understanding of the Electronic Blocks’ functionality
?? Frustration levels

In exploring the validity of the second research question, the evaluation assesses whether the blocks are a resource that children can use to explore simple programming concepts. In essence the analysis determines whether the children can program with Electronic Blocks.

Specifically, the analysis should explore the extent to which preschoolers:

?? Understand the syntax of the Electronic Blocks
?? Create simple working program stacks
?? Debug their program stacks
?? Re-use “code” fragments

5.1 Experimental Methodology

The preschool evaluation of Electronic Blocks took place at an on-campus university preschool. Twenty-eight children aged between 4 and 6 years participated in the evaluation. Six experimental sessions spanning two weeks were conducted and each session lasted between 60 and 90 minutes.

The Electronic Blocks evaluation in the preschool environment has utilised direct observation methods of data gathering. These methods primarily involve naturalistic observation. In general it is acknowledged that observation is the only practical research process in early childhood education as it provides a more realistic picture of behaviour or events than do other methods of information gathering (Irwin & Bushnell, 1980; Hutt & Hutt, 1970; Brandt, 1972; Medinnus, 1976). Direct observation involves observing behaviours or events occurring in natural settings without trying to control or manipulate factors that might influence the behaviour being studied (Irwin & Bushnell, 1980). It aims to study freely occurring behaviour in natural settings where there is nothing artificial or contrived.

At each session the Electronic Blocks were set up in an area within the indoor play area. Three complete sets of Electronic Blocks – 30 blocks in total – were provided at each session. A video camera and audio equipment were used to record children's interactions with the blocks. All children within the Preschool Room were free to participate in the study. However, due to the number of Electronic Blocks available, a limit of four children using the blocks at any time was imposed. The investigator actively participated in all evaluation sessions, providing children with ideas on how they might use the blocks, answering their questions and helping them to solve problems.

During the informal free-play sessions the investigator showed any new participants examples of simple sensor-logic-action block combinations and explained the functionality of each of the blocks.

6 Evaluation Results

6.1 Patterns of Usage

Of the 31 preschoolers who attended the preschool over the period of the evaluation, 28 chose to participate. Of the preschoolers who used the Electronic Blocks, 71% used the blocks on more than one occasion. Of the remaining children 50% were unable to return for a follow-up session, as they were only at the preschool for one day of the evaluation. Children on average played with the blocks between two and three times during the six days of evaluation. Five of the twenty-eight children returned four times.

The average amount of time each child spent playing with the blocks in a single session was 15 minutes. The longest time spent playing with the blocks in one session was 47 minutes while the shortest length of time was three minutes.

The average amount of time each child spent playing with the blocks over the entire evaluation period was 33 minutes. The minimum amount of time spent with the blocks was 5 minutes, while the maximum was 1 hour and 39 minutes.

6.2 Productivity

The "productivity" of each child using the blocks was determined based on a preliminary analysis of the video data. Productivity was calculated as the number of working block stacks children built during their time interacting with the blocks. The video evidence shows that on average each child built a working block stack every two and a half minutes. While two children failed to build anything during the evaluation period, other children built block constructions at an increased rate. Two children managed to build a working construction every minute they were involved in the evaluation. Construction included adding a block or blocks to an existing stack or creating a stack from scratch.

It is interesting to note that while some children were avid builders others were content to build one particular structure and play with that for a long period of time. One example of note is where a one child built a remote control car and then played with it for 15 minutes.

Another noteworthy issue is that three of the children were primarily interested in building interesting structures with the blocks with no consideration for what the outcome would be. The more blocks they could pile on top of one another the better. In one session, one child went a step further and added other articles from the environment – a piece of mesh found on the floor, a bell from the music area and a piece of string.

6.3 Understanding Block Functionality

The video footage provides clear evidence that the children are, in general, able to understand the functionality of the sensor and action blocks. However, there are examples of misconceptions in this area. The most common error involved children trying to get an action block working without a sensor block attached, or children trying to trigger a sensor block attached to an action block with an inappropriate signal (e.g. triggering a hearing block with light). The investigator constantly stressed to the children the need to have a "yellow block" (a sensor block) in their stack.

Many of the children struggled with the functionality of the logic blocks. The *and* block was used on very few occasions and in those instances when it was used, it was used to create either giant block stacks with no clear purpose or its use was instigated by the experimenter. The *delay* block was used sparingly.

The children, especially those who returned on more than one occasion, used the *not* blocks and the *toggle* blocks effectively. The *not* blocks were useful in that they created more action than they stopped, making more dynamic and interesting creations. The *toggle* blocks were set up as effective on-off switches.

The children especially enjoyed creating interacting block stacks, remote control cars, in particular. The enjoyment seemed to stem from the complexity of their construction. The children felt empowered to have made an artefact with many interacting elements.

7 Discussion

7.1 Meeting Design Goal 1

Levels of enjoyment

Levels of enjoyment can be ascertained largely by positive attitudes exhibited by the children while they were using the Electronic Blocks. They all appeared to have fun! Given that the children were free to come and go as they pleased, the data on time spent playing with the blocks (an average of 15 minutes for each encounter) reflects this enjoyment.

Enjoyment was exhibited in a number of different ways. Some children liked to create a single construction and then play with it for an extended period of time. In contrast other children enjoyed creating, adding to creations, pulling creations apart and then building something else. A small number of children were content to watch the other children play with the blocks, for periods of time from 3 to 10 minutes.

In addition, the responses by children during group time on the last day of the evaluation indicated that they found the Electronic Blocks fun to use, although 40% of the children acknowledged that they found the blocks challenging ("a bit tricky").

When asked to comment about what they enjoyed most, the responses entirely comprised of output behaviours the children were able to produce. They were excited about the cars they were able to make move, the remote controls that they built to do so without direct contact with the vehicle, and the torches they were able to create with a light block and some kind of sensor input. It is concluded from these responses that the children's enjoyment primarily stems from their ability to create their dynamic systems which interact with the physical world.

Levels of Attention and Interest

Over the period of the evaluation, 28 out of the 31 preschoolers in the centre voluntarily played with the blocks. The average amount of time spent with the blocks over the six sessions, was 33 minutes with maximum of one hour and 39 minutes. This demonstrates a noteworthy level of interest in the Electronic Blocks environment, particularly when you consider that only four children could use the blocks at one time. Only three children of the twenty-eight children who used the blocks failed to become engaged in the Electronic Blocks environment.

The children remained interested in the blocks for the duration of the evaluation. A majority of the children choose to play with the blocks on more than one occasion, with most children participating in the evaluation two or three times. The average length of time spent with the blocks in a single session – 15 minutes – is remarkable for the age group. The programming achievements outlined in the next section are made possible by the depth of engagement in the activity.

Understanding of the Electronic Blocks' functionality

Of the twenty-eight children involved in the Electronic Block evaluation, three failed to gain an understanding of the functionality of the sensor blocks and the output blocks. These children were content to watch other building with the blocks, but did not feel inclined to do so themselves. This emphasises the importance of engagement in development of understanding.

The concept that caused the greatest difficulty was that of inputs and outputs and the idea that the behaviour of the action block is reliant on some signal from a sensor or a logic block. Once the children understood this concept they were able to build any number of exciting creations.

The input-output relationships of the blocks are not directly visible, and must be discovered by exploration to be fully understood. The signals passed between blocks are "symbols" that are not readily grasped by the preshooler's pre-symbolic mind. This may account for the preschoolers' initial difficulty with this concept.

Fifteen of the 20 children who used the blocks more than once developed a basic understanding of the logic blocks, with the *not* and *toggle* blocks being used extensively during the evaluation. However, most children struggled to see how more complex and useful systems could be developed with the other logic blocks. They could not grasp the relationship between the invisible signals passed between blocks and the behaviours of the logic elements.

Instead, the children tended to build complexity by creating interacting block structures. With interacting block structures, input and output are visible and understandable. The reliance on visible interaction between the blocks is understandable in light of cognitive models of child development that characterise a typical preschooler as "sensory-dependent" (Bredekamp and Copple, 1997).

Frustration Levels

Very few children exhibited signs of frustration while using the blocks. Generally frustration was caused by the blocks' failure to produce the desired outcome. In a majority of instances this was due to a technical difficulty encountered by the child, a flat battery for example. On a few occasions the frustration was due to not understanding the functionality of the blocks. One notable episode occurred on the first day of the evaluation. Outgoing R created a sound activated car and in the process stated exuberantly "I love these". A few minutes later, failure to get a remote control car working elicited the response “I hate these”. One could argue that this is a “typical” response to technology when it works the way we want it to, and then when it doesn’t!

Summary of Aim 1

The Electronic Blocks are developmentally appropriate for preschool children. This is supported by the high level of enjoyment and engagement in the block construction tasks, and the demonstrated understanding of the blocks’ functionality. Frustration was generally confined to situations where the blocks had physically failed rather than inability to produce meaningful behaviour.

7.2 Meeting Design Goal 2

Understanding syntax

The physical affordances of the blocks enforce the simple syntax. The children were unable to create stacks where the function was undefined or ambiguous. This does not imply that all program stacks produced the desired or even useful behaviour, only that the blocks stacks were syntactically correct. Because of the use of physical affordances in an everyday play tool (blocks) the syntax required no explanation, and was immediately understood. The blocks have no buttons to press or rituals to perform to make them work; they simply embody their function

Creating simple working program stacks

The most important issue that needed emphasising was that an output block required input from a sensor block or a logic block before it would act. On numerous occasions during introductory sessions, the children would expect an output block to work without any input:

?? D on day 1 pointing a torch at a car block with no sensor and expecting it to move

?? J has a car with a touch sensor stacked on top – “Go go” she says.

?? M has made a car and attached three toggle blocks. “Go go” he urges!

Despite these misconceptions, a large majority of the construction occurring during the evaluation resulted in a working program stack. Each child built, on average, 10 working stacks of Electronic Blocks. While two children built none, two children built in excess of 20 during a single session with the Electronic Blocks.

While not all construction was understood, especially when involving logic blocks, children generated enthusiastic responses when their constructions produced some behaviour.

Debugging program stacks

There were some examples of debugging. The design of the Electronic Blocks easily allows children to see when an expected behaviour is not produced, but the cause of the bug is not always readily apparent. Debugging requires deep understanding of the nature of the blocks and their interactions. As the children gained more experience with the blocks, their confidence in debugging their code stacks increased. For example, R was given a movement block with a touch block on top. R had already put a touch block on a light block creating a torch. R tried to make the movement block go by shining his torch at it with no result. R carefully checked that the light was shining on the sensor. He then identified the problem with the sensor choice on the movement block and corrected it.

Reuse of “code” fragments

It was exciting to see many of examples of code re-use. During the initial sessions children would remove working sensor-logic combinations from structures that the investigator had used to demonstrate concepts, and create new structures. For example, S took a toggle-touch combination used as an “on-off” switch on a light block and implemented it as an “on-off” switch on a car block.

As children gained experience with the blocks they began to re-use working combinations of blocks. They would sometimes re-use sensor-logic combinations, sometimes, action-logic combinations. They began to realise that they could change the behaviour of their stacks easily by either altering the output or through changing the required input.

Summary of Aim 2

Children who became engaged with the Electronic Blocks were able to perform programming tasks. The physical nature of the blocks effectively enforced a readily understood syntax. Programming ability was demonstrated by the construction of working stacks, the ability to debug non-working stacks, and the re-use of “code” fragments.

8 Current Work

Evaluations of the Electronic Blocks with a class of 7-9 year olds have just completed, but detailed analysis of the data is yet to be performed. The preliminary results show a much stronger understanding of the block functions, with the use of the logic blocks occurring quite naturally. The students built amazing creations, such as towers of blocks that “talked” to each other, alarm clocks and cars that could count. When asked to indicate who would like to own a set of blocks all students enthusiastically raised their hands, as well as the teachers who raised both hands!

9 Conclusion

The educationally powerful exercise of programming is *not* restricted to the domain of keyboard, mouse and screen – it can be implemented as construction using tangible elements. Electronic Blocks are an example of how these elements can be created. Preschoolers can create simple programs readily, and learn rapidly from the physical interactions. Young children are ready to be engaged in the exciting world of computer programming – given the right interface.

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References

Bailey, J., and Weippert, H. (1991). Educational computing challenges for early childhood educators. Australian Journal of Early Childhood 16, 3, 28-33.

Beaty, J.J. (1984). Skills for preschool teachers. Columbus: Charles E. Merrill Publishing Company.

Brandt, R.M. Studying Behavior in Natural Settings. Holt, Rinehart and Winston, Inc: New York, 1972.

Bredekamp, S., and Copple, C. (Eds.). (1997). *Developmentally appropriate practice in early childhood educatio*n. (Revised ed.). Washington, D.C.: National Association for the Education of Young Children.

Frei, P., Su, V., Mikhak, B., and Ishii, H. (2000). curlybot: Designing a New Class of Computational Toys. *Proceedings of CHI'2000*, ACM Press, 129-136.

Hutt, S.J., and Hutt C. (1970). *Direct observation and Measurement of Behavior*. Charles C Thomas Publisher: Springfield Illinois.

Irwin, D.M., and Bushnell, M.M. (1980). *Observational Strategies for Child Study*. Holt, Rinehart and Winston: New York.

Kahn, K. (1996). ToonTalk[TM] – An animated programming environment for children. *J. Visual Languages and Computing 7*, 197-217.

Medinnus, G.R. (1976). *Child Study and Observation Guide.* John Wiley and Sons Inc: New York.

Papert, S. (1980). *Mindstorms: Children, computers and powerful ideas*. New York: Basic Books.

Resnick, L. (1987). *Education and learning to think*. Committee on Mathematics, Science, and Technology Education, National Research Council. Washington, D.C.: National Academy Press.

Resnick, M. Behaviour construction kits. *Commun. ACM 36*, 7 (1993), 65-71.

Resnick, M., Bruckman, A., & Martin, F. (1996). Pianos not stereos: Creating computational construction kits. *Interactions 3*, 5, 41-50.

Sheingold, K. (1987). The microcomputer as a symbolic medium. In R. D. Pea, & K. Sheingold (Eds.), *Mirrors of minds: Patterns of experience in educational computing* (pp 198-208). Norwood, NJ: Ablex Publishing Corporation.

Smith, D. C., Cypher, A., and Schmucker, K. (1996). Making programming easier for children. *Interactions*, September – October, 59-67.