Robot Building for Preschoolers

Peta Wyeth[1] and Gordon Wyeth[2]

[1] University of Nottingham, Jubilee Campus, Nottingham NG8 1BB, UK
[2] University of Queensland, St Lucia, Queensland 4072, Australia
peta.wyeth@nottingham.ac.uk,
wyeth@itee.uq.edu.au

Abstract. This paper describes Electronic Blocks, a new robot construction element designed to allow children as young as age three to build and program robotic structures. The Electronic Blocks encapsulate input, output and logic concepts in tangible elements that young children can use to create a wide variety of physical agents. The children are able to determine the behavior of these agents by the choice of blocks and the manner in which they are connected. The Electronic Blocks allow children without any knowledge of mechanical design or computer programming to create and control physically embodied robots. They facilitate the development of technological capability by enabling children to design, construct, explore and evaluate dynamic robotics systems. A study of four and five year-old children using the Electronic Blocks has demonstrated that the interface is well suited to young children. The complexity of the implementation is hidden from the children, leaving the children free to autonomously explore the functionality of the blocks. As a consequence, children are free to move their focus beyond the technology. Instead they are free to focus on the construction process, and to work on goals related to the creation of robotic behaviors and interactions. As a resource for robot building, the blocks have proved to be effective in encouraging children to create robot structures, allowing children to design and program robot behaviors.

Keywords: Educational robotics, robot construction kit, robot programming environment.

1 Introduction

Robot building and programming allows children to become creators of technology. As designers and builders of technology, children become more deeply engaged with technology education than they might from more conventional classroom activities. However it is only in recent years that classroom robot building has become possible for children in middle and secondary school, with the advent of resources such as the LEGO® RCX™ brick. Now, with these type of resources available, children from around the world have become engaged in robot building and programming, as evidenced by the success of programs such as RoboCup Junior.

In the specialist area of early childhood education there remains the challenge for educators to develop educational programs which include technology that is suitable to the unique needs and abilities of this age group. There are concerns about the

U. Visser et al. (Eds.): RoboCup 2007, LNAI 5001, pp. 124–135, 2008.

young children's physical and cognitive readiness to use computers and other technological artifacts. Robot building and programming is a case in point. Given that young children, between the ages of three and six years, are only just acquiring the rudiments of notational systems and struggle with symbolization in language, pictures, three-dimensional objects and pretend play [1][2][3], it is apparent that existing technology is unsuitable for all but the most gifted in this age group.

This paper details the use of Electronic Blocks designed for young children aged between four and eight. Electronic Blocks are a new resource for technology education which have been designed and built to provide an appropriate means through which young children are able to create and program simple robots. The paper describes the blocks, and illustrates their effectiveness from observations of a two week study of four and five year old children as they used the Electronic Blocks.

2 Background

In identifying the way in which technology should be used in early childhood education, Yelland [4] looks towards environments that are stimulating and encourage active exploration of objects and ideas. Such environments facilitate quality technology education – the technology becomes a resource which allows young children to be involved in the design and production processes to produce various outcomes. Resnick [5] agrees and asserts that the

Best computational tools do not simply offer the same content in new clothing; rather, they aim to recast areas of knowledge, suggesting fundamentally new ways of thinking about the concepts in that domain, allowing learners to explore concepts that were previously inaccessible.

Resnick and his group at the MIT media lab based their research on this philosophy. They started with the development of LEGO/Logo [6] which combined the LEGO Technic product with the Logo programming language. It was the first robotic construction kit ever made widely available [7]. Unfortunately, each construction built in a LEGO/Logo environment by necessity was connected to a computer via wires. This led to a lack of mobility and was the greatest limitation of LEGO/Logo [7].

The Programmable Brick is a successor to this research. The Programmable Brick is a tiny computer embedded inside a LEGO brick that children use to build systems that behave and respond to their environment [8]. Children included the Programmable Brick into their regular LEGO constructions and then wrote Logo computer programs to make their creations react and behave. The second generation of the Programmable Brick – the Red Brick – was specifically designed for robustness and ease of manufacture and this Brick was widely used in classroom settings [7]. The success of the Red Brick is highlighted by the final version of the Programmable Brick – the LEGO™ RCX® Brick which is now a commercially available product, and is widely used by children in robot competitions such as RoboCup Junior.

A construction kit called Cricket was developed as a successor to the Programmable Brick. Crickets are small Programmable Bricks that, in addition to connecting to motors and sensors, can communicate with each other via infrared light [8]. The communication ability of Crickets allows children to think about systems of communicating entities and explore the behaviors that arise from Cricket interactions. Like the Programmable Brick, Crickets are fully programmable with children being able to write and download computer programs into the Crickets from a desktop computer [9].

The development of *curlybot*, under the direction of Hiroshi Ishii at MIT, has occurred in parallel to the development of Crickets. *curlybot* is aimed at children in their early stages of development - ages four and up [10]. It is an autonomous two-wheeled vehicle with embedded electronics that can record how it has been moved on any flat surface and then play back that motion accurately and repeatedly. Children can use *curlybot* to develop intuitions for advanced mathematical and computational concepts, like differential geometry, through play away from a traditional computer [10]. In preliminary studies conducted by the developers of *curlybot*, they found that children learned to use *curlybot* quickly.

3 Electronic Blocks

Electronic Blocks aim to provide the same rich robot building and programming experiences as the Programmable Brick, but with intuitive tangible interface of *curlybot*. The Electronic Blocks are physical building blocks of a size and shape familiar to the target age group (LEGO® Duplo™ Primo™ blocks). The programmability and intelligence of the blocks has been created by placing electronics inside. Some blocks have sensor inputs and others have action outputs. When connected together, the output of sensor blocks control the input of action blocks. Logic blocks can act as intermediary structures to change the effect of a sensor. Any number of blocks can be stacked together to create a huge variety of robotic vehicles and structures that interact with the environment and each other.

3.1 Functional Design

There are three kinds of Electronic Blocks: sensor blocks, action blocks and logic blocks. Sensor blocks are capable of detecting light, touch and sound. Each block has an input attached to its upper connector and an output attached to its lower connector (see Figure 2). The input is off unless it explicitly receives an on 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 in any way on an action block, any sensor input will trigger the action block.

Action blocks produce some kind of output. The *light* block produces light, the *sound* block produces sound and the *movement* block is capable of motion. All action blocks have two connectors on top, each capable of triggering the action; both inputs are ORed together to produce the output. They are physically constrained by a base plate with no connectors so that they cannot be placed on top of another block and have to be positioned at the bottom of a block stack.

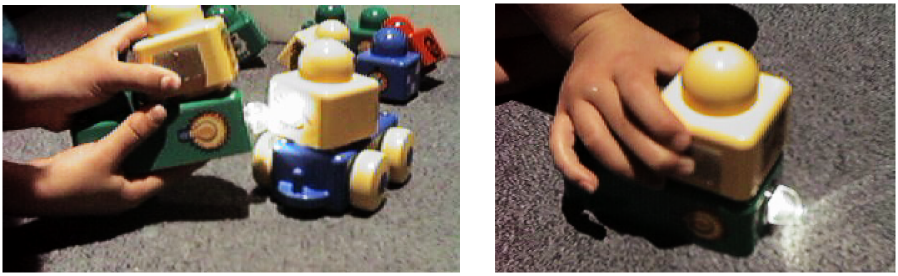

Fig. 1. The Electronic Blocks in action - a remote control car built from the blocks. The child has built a torch from a touch and light block (close-up on right), which is being used to trigger a light sensor on a motion block.

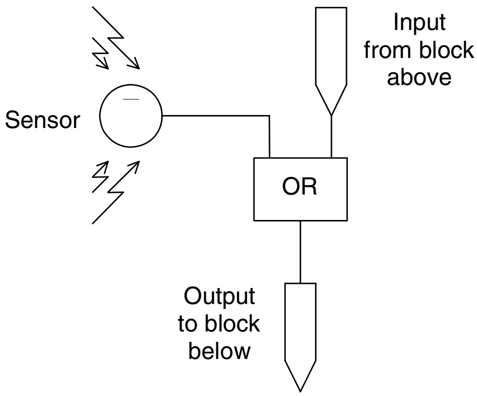

Fig. 2. The functional implementation of a sensor block. The sensor is ORed with any signals from blocks above.

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*).

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. The *and* block has two inputs and two outputs. The *and* 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.

3.2 Physical Block Design

All sensor blocks are yellow. Readily understandable icons identify the different functions of the sensing blocks: for example, an eye for a seeing 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. Each different logic block type has distinctive icons and colors 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".

Fig. 3. The complete set of Electronic Blocks. The sensor blocks are to the left, the logic blocks are in the centre and the action blocks to the right.

3.3 Electronic Block Communication

Electronic Blocks are designed so that there is no need for children to attach wires or fix connectors to enable blocks to pass signals from one to the next. Each of the block's upper connector (or connectors) corresponds to a dome on the LEGO blocks. A block's lower connector (or connectors) is found in the hollow at the base of the block. Electronic Block communication is achieved optically, allowing for imprecise positioning of one block on the other.

4 Preschooler's Interactions with Electronic Blocks

One study of the Electronic Blocks was specifically designed for preschool children, aged between 4 and 5 years. This study was primarily focused on assessing the extent to which the Electronic Blocks allowed children to build and program simple robots. The study for this age-group is structured in such a way as to observe the children using Electronic Blocks in a natural, open-ended, free-play setting. It took place at a University Campus Preschool with twenty-eight children aged between four and six years. Fifteen of the participants were female, thirteen were male.

4.1 Study Procedure

The study spanned two weeks. Three sessions per week were conducted and each session lasted 90 minutes. For each session the Electronic Blocks were set up in an area within the indoor play area. 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, helping them to solve problems, and encouraged working in pairs or groups.

Before the first of the six sessions the Preschool teacher introduced the researcher to the children and the intention of the study was simply explained. The Electronic Blocks were then demonstrated to the entire group, with the functionality of each block briefly explained. Initial explanations of the Electronic Blocks primarily focused on the sensor blocks and action blocks. The idea was to introduce participants to the less complex Electronic Block concepts. Children were provided with the opportunity to become familiar with the functionality of these blocks before moving on to the more complex combinations involving logic blocks. By sessions 5 and 6, the involvement of the researcher was reduced. While available to help them if they ask for assistance, the researcher did not play an active role in stimulating the children's play experiences with the blocks.

4.2 Preschool Observations

The video of preschoolers using Electronic Blocks was examined to obtain usage analysis of the preschoolers' interactions with the blocks. Specifically, the video was analyzed to determine:

- the number of times each children interacted with the Electronic Blocks;
- the duration of interactions with Electronic Blocks; and
- the number of structures children built while using the blocks.

This data has enabled an evaluation of the Electronic Blocks to determine whether they were an effective resource for robot building and programming. Specifically, the data has been analyzed to determine the preschoolers'

- patterns of usage,
- interactions with the blocks,
- level of involvement in building a variety of constructions, and
- level of understanding of Electronic Block functionality.

Patterns of Usage

Of the 31 preschoolers who attended the preschool over the period of the evaluation, 28 chose to participate. Fifteen of the participants were female, thirteen were male. Of the preschoolers who used the Electronic Blocks, 20 used the blocks on more than one occasion. Children on average played with the blocks between two and three times during the six days of evaluation, with females visiting the blocks slightly more frequently (an average of 2.5 visits for the females versus 2.3 visits for the males).

The average amount of time each child spent playing with the blocks in a single session was 15 minutes. Females spent an average of 12 minutes interacting with the Electronic Blocks in a single session, while males, on average, interacted with the blocks for 18 minutes in a single session. The longest time spent playing with the blocks in one session was 47 minutes while the shortest period of time was two minutes. Overall average length of visits remained reasonably consistent across visits, ranging between 11 and 16 minutes.

Interactions with Electronic Blocks

The video evidence shows that on average each child built a working block stack every two minutes. While one participating child failed to build anything during the evaluation period, other children built block constructions at an increased rate. Construction included adding a block or blocks to an existing stack or creating a stack from scratch. On average, girls created a different structure every two and a half minutes, and boys created one every one minute and forty seconds. It is interesting to note that while some children were avid builders others were content to build one particular structure and play with it for a long period of time. One example of note is where one child built a remote control car and then played with it for 15 minutes.

In general, boys were involved in building more structures than girls. On average, boys built 21 structures over the duration of the evaluation while girls built 10 structures. The girls built, on average, five structures per visit, while the boys build 10 structures per visit.

There were examples where children were observed using the Electronic Block structures to stimulate other play. The construction of Electronic Block structures did not appear to be their primary activity but rather an activity which complemented their pretend play adventures. Another noteworthy issue concerns construction activities which are primarily about process rather than outcome. There were some children who were not concerned with the output they produced and the act of construction was their motivation for taking part. In these cases the children tended to build elaborate stacks of blocks, the largest stack consisting of thirteen blocks. The children were primarily involved in building interesting structures with the blocks with no consideration for what the outcome would be.

Types of Construction

The children were involved in a wide variety of construction activities using the range of Electronic Blocks. Analysis of the video data indicates that the *movement* block was the action block of choice. While the *light* block was also popular, children were more likely to create structures with car bases than with the other two action blocks. All children who interacted with the blocks created a moving vehicle at some stage in their construction activity. The sensor blocks appeared equally popular. Children used the *seeing*, *hearing* and *touch* blocks to activate the *movement* blocks, and many were successful at creating a "remote control" car using a *seeing* block attached to the *movement* block and then activating a separate *light* block to make the car move. This became very popular and for over 70% of the evaluation period at least one child was playing with a remote control vehicle that they had built.

The *toggle* and *not* blocks were used on more occasions than the other logic blocks. The children would often use *not* blocks to activate their action blocks. Children would use the *toggle* block when they did not want to keep providing an environmental stimulus for some action block. Some children also enjoyed using *delay* blocks but the *and* block was used sparingly throughout the evaluation.

A large majority of the constructions undertaken by the children contained either two or three blocks. Very few structures were built which had five or more blocks. The addition of blocks to structures, particularly logic blocks, in some cases confused the children, and as the study progressed children built large stacks less frequently. The data captured shows that initially children were willing to build large stacks with four or five blocks, but this tended to drop off once children began to grasp the functionality of the blocks.

4.3 Case Study: Ben and Kathy

In addition to the usage analysis, a case study of two preschoolers using the Electronic Blocks has been included to highlight salient points. This case study is based on the preschool video footage.

Ben has put a touch block and a seeing block on a movement block. He touches it to make it move. Kathy has built a car with a touch block on it also. She pulls the touch block off and as she picks up a seeing blocks she says "and an eye one". "I need a torch" she says picking up a light block. Ben takes the touch block off his car and places it on a light block. Kathy places a touch block on top of her torch then touches it and checks that the light is working. She shines it at the seeing block to make her car move. Ben shines the torch he has made at his seeing block. His car moves.

Kathy takes the touch block off her torch and the seeing block off her movement block. She moves over to the box where all the Electronic Blocks are being stored. "Ben, wanna see these ones?" she asks as she picks up a not block. Ben takes the touch block off his light block. "I'll show you what these ones always do" says Kathy. She places the not block on a movement block and states, "They just make the car go." The car moves across the mat.

Ben leans over and takes the not block off the car. He tries puts it on his movement block (it still has the seeing block attached). "They're a non … they're a non block … they're a non stop block," says Kathy. The seeing block on Ben's car has skewed slightly making it difficult to slip the not block on to the spare hump. Ben gives up trying and places it on a sound block and then on a light block.

Kathy goes to the Electronic Blocks box and picks up a toggle block. She says to Ben "If you put it on it just goes and if you take it off, it stops!" illustrating her point by placing the toggle block on a movement block and then taking it off. The movement block moves when the toggle is attached. Ben picks up his torch (the not block with the light block) and takes it over to his car. He shines the light at the seeing block to make the car move.

Seven of the ten types of Electronic Blocks were used in the case study. The children didn't use the *hearing* block, the *and* block or the *delay* block. They used 13 blocks in total, a majority of which were sensor and action blocks. The constructions built during the case study include:

- A simple input/output stack created by Ben. This stack had a car base that was touch activated. The inclusion of a *seeing* block also meant it could have been light activated. Later in the case study, Ben built a touch activated torch, and consequently has transformed this input/output stack into an interacting block system.
- A simple touch activated car created by Kathy. This is an example of a simple input/output stack.
- An interacting block stack built by Kathy. The first stack was a touch activated light and the second structure was a *seeing* block stacked onto a car base.
- Two Electronic Block stacks that utilize logic created by Kathy. On both occasions Kathy uses a car base. In the first instance she stacks a *not* block on her *movement* block, on the second occasion she uses a *toggle* block.
- Output blocks activated by the *not* block. Two such stacks (on containing a *sound* block, the other a *light* block) were built by Ben.

The construction that took place in the case study is typical of the types of construction which took place during the Electronic Block study. Children were more likely to build complexity into their constructions by creating interacting block stacks or simple logic stacks. There were fewer examples of children building complexity into their constructions with the use of logic block combinations.

5 Discussion

Young children aged between three and six learn best while actively manipulating and transforming real materials. 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 [11]. Electronic Blocks aim to address this issue. Unlike the computer and many other media used for technology education, the design of the Electronic Block allows both the input and the output to be physical. Of the interactive programming environments developed for use by young children, *curlybot* [10] is perhaps the only other resource in this category. However *curlybot* embodies a programming-by-demonstration while the Electronic Blocks allow children to create technological knowledge through constructive processes.

5.1 Understanding Block Functionality

The video footage provides clear evidence that the children were, in general, able to understand the functionality of the sensor and action blocks. The successful and repeated construction of working Electronic Block stacks reflects children's understanding of the resource. The case study demonstrates that both Kathy and Ben, for example, have a solid understanding of the ways in which sensor and action blocks work and the ways in which such stacks can be built to interact not only with the environment but also with each other. Of the twenty-eight children involved in the Electronic Block evaluation, only two failed to gain an understanding of the functionality of the sensor blocks and the action blocks. One of these children was content to watch others building with the blocks, while the other only built one Electronic Block structure.

The data presented provides evidence that the children felt most comfortable using sensor and action blocks to create simple structures, of both a stand-alone and interacting nature. Children mostly used logic blocks in simple stacks with an input, an output and the logic block in between. *Not* and *toggle* blocks were primarily used to support the construction of interacting block stacks.

Despite the successes children had in creating working sensor-action constructions, there are examples of misconceptions in this area. The most common error involved children trying to get an action block working without a sensor or logic block attached, or children trying to trigger a sensor block attached to an action block with an inappropriate signal. The investigator constantly stressed to the children the need to have a "yellow block" (a sensor block) in their stack. On numerous occasions during introductory sessions, the children would expect an output block to work without any, or with incorrect, input. The concept of inputs and outputs and the idea that the behavior of the action block is reliant on some signal from a sensor or a logic block caused children the greatest difficulty in their construction activities. Once the children understood this concept they were able to build any number of exciting creations and for those creations to exhibit the desired behaviors.

Fifteen of the twenty children who interacted with the blocks on more than one occasion became engaged in using the logic blocks, with the *not* and *toggle* blocks being used extensively during the evaluation. The *not* blocks were useful in that they created more action than they stopped, making more dynamic and interesting creations. Kathy introduced the *not* block to Ben in the case study. Her explanation and demonstration of its behavior indicated some understanding of the functionality of the *not* block. The *toggle* blocks were set up as effective on-off switches.

Many of the children struggled with the functionality of the logic blocks. Towards the end of the case study Kathy used a *toggle* block to make a car go without a sensor block. This worked in this instance because the *toggle* block was "switched on". This is not always the case. Kathy's corresponding comments indicated that she did not understand that sometimes the *toggle* block would be "off". The case study provides an insight into the difficulties that preschool children sometimes had when using the *toggle* block. The *toggle* block can be in one of two states: on or off. A child can't tell by just looking at the block which state the *toggle* is in. Only by observing the behavior of an action block that has a *toggle* block attached can the state of the toggle be determined. There was only a few examples of children showing clear understanding of the functionality of the *and* and *delay* blocks.

5.2 Play and Electronic Blocks

The Electronic Blocks study showed that children were interested in interacting with the blocks and enjoyed doing so. Time spent playing with the blocks reflected this interest and enjoyment. Significantly, the children remained interested in the blocks for the duration of the study. The study data highlighted the flexibility of the Electronic Blocks and their ability to appeal to children with different ability levels, interests and interaction styles. Many children appeared to become strongly engaged in Electronic Block activities. 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 appeared that the children's enjoyment primarily stemmed from their ability to create their dynamic systems which interact with the physical world.

6 Conclusion

The Electronic Blocks were designed to address the challenge of developing a technology to allow preschool children the experience of constructing artificial agents, while addressing the unique needs and abilities for children of preschool age. The preschool study has shown that the Electronic Blocks interface is well suited to the needs of young children. Children are free to autonomously explore the functionality of the blocks as the complexity of the implementation is hidden from them.

Interaction with the Electronic Blocks primarily utilizes unstructured exploratory learning. Children's interactions with the blocks are best categorized as play. This play operates at several levels – the programming of a robot through a construction activity, the use of that agent in a variety of pretend play situations, and the ongoing creative revision of that agent. The Electronic Blocks are a resource which young children use to design, build and evaluate a large variety of robotic artifacts. They become creators of technology. In the process children become involved in meaningful technology education.

References

1. Santrock, J.W.: Child development, 8th edn. McGraw Hill, Boston (1998)
2. Shaffer, D.R.: Developmental Psychology: Childhood and adolescence. Wadsworth Group, Belmont (2002)
3. Sheingold, K.: The microcomputer as a symbolic medium. In: Pea, R.D., Sheingold, K. (eds.) Mirrors of minds: Patterns of experience in educational computing, pp. 198–208. Ablex Publishing Corporation, Norwood (1987)
4. Yelland, N.: Technology: changing the way we think and learn or maintaining the status quo. Australian Educational Computing 12(1), 3–8 (1997)
5. Resnick, M.: New Paradigms for Computing, New Paradigms for Thinking. In: di Sessa, A., Hoyles, C., Noss, R. (eds.) Computers and Exploratory Learning, pp. 31–43. Springer, Berlin (1995)
6. Resnick, M., Ocko, S.: LEGO/Logo: Learning Through and About Design. In: Harel, I., Papert, S. (eds.) Constructionism, Ablex Publishing, Norwood (1991)
7. Martin, F., Mikhak, B., Resnick, M., Silverman, B., Berg, R.: To Mindstorms and Beyond: Evolution of a Construction Kit for Magical Machines. In: Druin, A., Hendler, J. (eds.) Robots for Kids: Exploring New Technologies for Learning Experiences, pp. 9–33. Morgan Kaufman, San Francisco (2000)
8. Resnick, M., Martin, F., Berg, R., Borovoy, R., Colella, V., Kramer, K., Silverman, B.: Digital Manipulatives: New Toys to Think With. In: Proceedings of the CHI 1998, pp. 281–287. ACM Press, Los Angeles (1998)

9. Resnick, M., Berg, R., Eisenberg, M.: Beyond Black Boxes: Bringing Transparency and Aesthetics Back to Scientific Investigation. Journal of the Learning Sciences 9(1), 7–30 (2000)
10. Frei, P., Su, V., Mikhak, B., Ishii, H.: curlybot: Designing a New Class of Computational Toys. In: Proceedings of CHI 2000, pp. 129–136. ACM Press, The Hague (2000)
11. Resnick, M., Bruckman, A., Martin, F.: Pianos not stereos: Creating computational construction kits. Interactions 3(5), 41–50 (1996)