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Intelligent Physical Blocks for Introducing Computer Programming in Developing Countries

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Abstract: This paper reports on the evaluation of a novel affordable system that incorporates intelligent physical blocks to introduce illiterate children in developing countries to the logical thinking process required in computer programming. Both the usability and educational aspects are reported on. We provide a brief overview on previous work in this field. Results obtained from field studies are given. We conclude with recommendations for improvements and further research.

Keywords: GameBlocks, illiterate, programming, physical blocks, education, usability, developing countries, pre-school.

1. Introduction

Perhaps the greatest stumbling block to entry into the domain of Information and Communication Technologies (ICTs) among young people in developing countries is the lack of informal exposure to personal computers. It can be argued that formal exposure to ICT is not ideal in all current education systems. Some current education systems are biased in favour of good/photographic memory abilities, allowing a candidate to pass a subject without a true understanding of the contents. A better system could be the informal exposure to the learning subject, outside of the classroom, making it part of the child's recreation activities instead of a formal learning experience. It has previously been reported that children learn better when they are exposed to fun activities, rather than as a formal lesson.

Three-dimensional vision is learned [1, p51], enabling us to perceive it through two-dimensional media such as written text. Hannaford calls this visual literacy. People who have not yet mastered it are unable to interpret a drawing of a mountain as such. They only notice the colours and lines on a piece of canvas, but not the texture or perspective. Learning is done best when multiple sensors are involved. Learning through reading two-dimensional text or listening to a teacher limits the learning experience. In contrast, learning through experience combines senses, emotions, and movements that involve the learner fully [1, p5]. Touch, specifically, is a major contributor to fully understanding vision. [1, p50] Our system exploits this knowledge about learning by providing a tangible interface that controls another tangible object. This helps make the learning concrete.

We support the thinking of others [2, p3][3, p364] who question whether perhaps the way ICT is taught should be adapted to the local context.

The system reported on here is aimed at introducing young children to programming where it is more important to gain experience with simple programmes, rather than more

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complex ones [4, p20]. Its aim is to introduce young children to the basic logical thinking required for writing computer programmes, but without the requirement of first learning to read and write, operate a computer, using a computer keyboard, typing, saving the code, compiling it, downloading, and then executing the instructions. The system aims to bypass all these literary requirements, making a direct link from logical thought to physical execution. This is done using simple electronic circuitry, removing the requirement for a traditional and relatively expensive, fragile computer in the form we have come to know as the Personal Computer. This makes it particularly suitable for developing countries due to its affordability.

Our approach is supported by Papert [5, p23] where he states "It is … not necessary to work with computers in order to acquire good strategies for learning".

It can also be argued that the system supports "kinaesthetic thinkers" [4, p17] better than traditional keyboard-based programming in exercising the logical thinking process.

We admit that there are currently limitations to the system. For instance there is no simple way to restore a previously-coded programme, or implementing complex coding structures. But after all, the aim of this system is to introduce young children to the creative and logical process of simple programming.

2. Prior Work

Other systems using physical objects have previously been developed [3][4][6][7][8][9][10][11], either using electronic components inside the objects themselves, or using optical cameras to "read" identifying information off the objects. Our system offers the distinct advantage of reducing the cost of the blocks significantly in that only magnets are used inside the blocks to represent their functionality, albeit with reduced functionality. We believe that this approach is more appropriate for developing countries because of the resultant significant monetary savings.

3. Objectives

We tested the GameBlocks [14][15] system's usability and educational value when used to teach illiterate children the principles of basic programming.

The usability outcomes evaluated, based on ISO 9241-11 [12], are firstly the effectiveness (degree of task completion), secondly the efficiency (how much effort it takes to complete a task), and thirdly the satisfaction (positive attitudes toward the product and freedom from discomfort) in which the user can use the system to achieve a pre-determined goal.

The educational outcomes that were evaluated are the ability of the testees to firstly compile a sequence of instructions in the correct order from those available, secondly the correct translation by the testees of the written instructions into the symbols on the cubes, thirdly the testees placing the cubes onto the trays in the correct sequence, and lastly to understand how the instructions represented by the cubes are transferred to the toy robot [13].

4. Technology Description

GameBlocks is a system consisting of acrylic blocks (Figure 1), trays (Figure 2), and controlling electronics that enables an illiterate child to compile simple physical sequences to control a toy robot (Figure 3). Each 3-dimensional block is colour-coded and has a symbol on its top surface. Together, the colour and the symbol both represent the function the toy robot would execute. The user chooses, from the available blocks, the sequence of movements the toy robot has to execute, and places them in that same sequence on the trays

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(Figures 4,5). As the electronic circuit interrogates each block sequentially, an appropriate command is sent to the toy robot for interpretation and immediate execution (Figure 6).

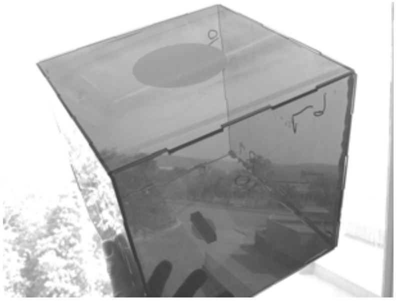

Figure 1. Acrylic block.

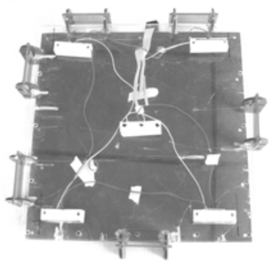

Figure 2. Tray.

Figure 3. Humanoid toy robot.

Figure 4 (left) and Figure 5 (right). Children placing the blocks on to the trays.

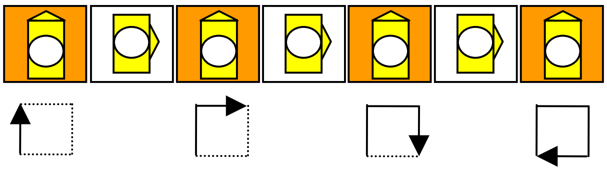

Figure 6. (top)Physical sequencing (left to right) example of 7 blocks as viewed from above. (bottom) The resultant movement over time (left=start, right=end) of the toy robot as viewed from above.

5. Methodology

Multiple workshops were held at two science events, with groups of approximately 20 children participating in each workshop. Some of the workshops were formally evaluated. During the formal evaluation in the order of 30 children participated. During the informal evaluation sessions approximately 50 children were observed.

5.1 Formal evaluation

A company external to our institute was contracted to provide an independent report on the system and the children's interaction with it. The workshop was run in a venue normally used for dancing rehearsals, with a wooden floor and the walls and ceiling painted black. One wall was completely covered by a mirror. Supporting project team members were present during the tests, positioned behind the testees and having a clear view of the activities. Verbal comments given by the supporting team members after each experiment served to inform this paper and the resultant formal report [13]. Although written instructions were used in the tests, we believe that the outcomes would be no different if only symbols had been used instead.

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5.2 *Preparation*

Prior to each evaluation, four robot movements were written on strips of white paper approximately 30x15cm in size (Figure 7), one movement per strip. The wording on the strips were: “Forward”, “Backwards”, “Left”, and “Right”.

Figure 7. Pseudo- code strips.

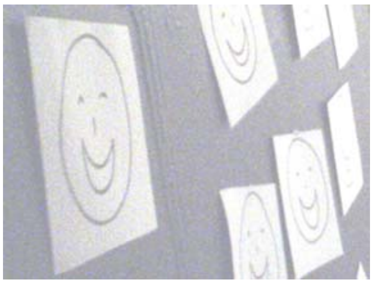

Figure 8. Symbols used for evaluation.

These represented forward, backward, left, and right toy robot body motions. Although six toy robot movements are supported by the system, only these four were made available for the evaluation. Two acrylic blocks and two paper strips for each movement instruction were used in the test, allowing for a total of eight possible instructions.

Also on separate paper strips, approximately 15cmx15cm in size, happy and unhappy faces (Figure 8) were drawn. These would later be used to denote the success or failure of a step in the test. Prior to the testing these paper strips were randomly stuck to the nearby wall using sticky putty (Figure 7). The sticky putty allowed for easy repositioning of the paper strips later.

The trays were placed side-by-side in a singular row, and the blocks interpreted sequentially from left to right as faced by the testee (Figure 6). Once the testee had completed placing the blocks onto the trays, a verbal indication was given to the facilitator. Interpretation by the electronic circuitry commenced when the facilitator switched the system on. Alternatively, the system makes provision for immediate execution when a block is placed onto a tray, but this mode of operation was not evaluated.

Both still- and video-cameras were utilised during the sessions to aid in later analysis of the tests. The two camera operators would roam the test area so as to capture images from the best vantage point.

Figure 9. A tester takes notes (to the right at a table) while the facilitator (to the left) assists atesteer (centre) in deciding where to place a block onto the trays with other seated testees waiting their turn (foreground).

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On the floor, in front of where the testees were seated in a semi-circle facing the instructor, were the trays, blocks and controlling electronics (Figure 9). The trays were connected to the controlling electronics with wires. The blocks were randomly positioned together on one side of the set-up, with no particular meaning in their configuration. However, they were all orientated so that the symbols on the top of the blocks were facing upwards. Some blocks were stacked on top of others.

5.3 Reception and privacy

There was no pre-selection possible during these events. Children arrived by bus from neighbouring areas and attended the workshops without having had any a-priori contact with the researchers. In each instance the group would comprise children from a single school, accompanied by an adult who took responsibility for them.

Upon arrival at the workshop entrance, the following formalities were taken care of. Firstly a consent form was required, signed by the adult accompanying the children. This form included information about the purpose of the experiment, and the way in which the child's rights would be protected. For example, the child's identity would not be made known in subsequent reports. Identity includes the child's name and face. It was also stated that any published results would not be connected to the individual and the individual would not be identifiable by the results. This consent was required for the group and not per individual in the group. Secondly each child had a large (approximately 10cmx10cm) white paper label with the child's age pinned to the chest region (Figure 10). This visual information could later be used in analysing the video footage.

Figure 10. A tag with the user's age would later aid in the analysis of the video material.

5.4 Measurement

The testee first identified the instruction (pseudo-code) to be executed. These were then placed on the wall in the desired sequence, visible to all testees (Figure 11). When satisfied with the sequencing, the testee placed a corresponding block on a tray (Figures 4,5,9). When satisfied that all the blocks have been placed in the required sequence as indicated by the pseudo-code, the testee signalled the facilitator. The facilitator then activated the electronic circuitry and the commands were sent sequentially to the toy robot for execution. As each instruction was executed, the help of all testees was elicited to verify that the movement corresponded to the pseudo-code. If it did, a paper strip with a smiling face was positioned below the relevant instruction on the wall. If it did not, an unhappy face was used instead. This was later used to determine the effectiveness of the system.

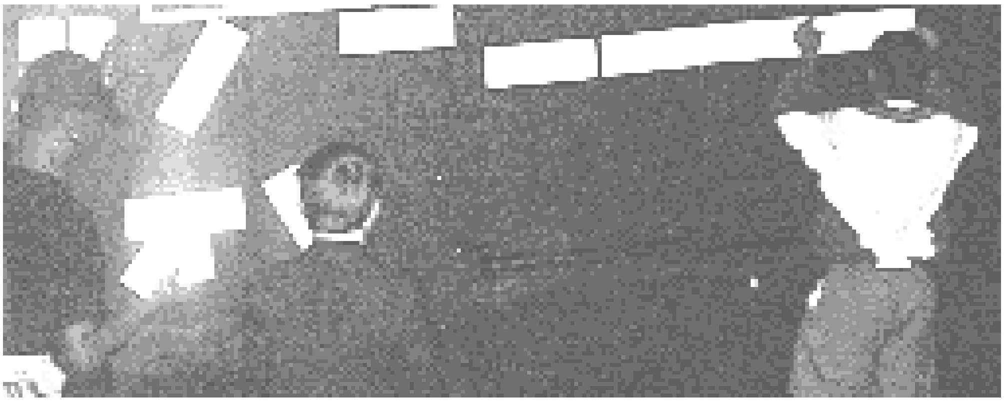


Figure 11. A user(right) places pseudo code in the desired sequence on the wall.

5.5 Instructions

English was used as the instruction medium. Although some testees had another mother tongue, they could all converse in English to varying degrees. Having taken their positions in no particular order around the already set up equipment, they were welcomed by the test supervisor team member. At this point they were briefly introduced to the project and the purpose of the test. It was explained that they were participating in a test to measure the usability- and educational-value of the GameBlocks, that there was no right or wrong way to participate, that their inputs would be considered to improve on the current design, and that their identity would be protected. They were informed that a video recording as well as still photo shots would be taken during the session.

The tester then introduced the technical expert who managed the rest of the experiment. The tester, camera operators, and rest of the team members observed the proceedings that followed in silence from a distance.

The approach taken by the technical expert was very different to that of the tester. The expert provided another perspective on the project to the children, explaining that the aim was to develop an interest in science and technology amongst young school-going children. At this stage the various components of the system were introduced.

In both cases the test supervisor and technical expert kept the introduction to the system brief, pointing out the system components to the testees and giving a short verbal explanation on how to use it. This was done in order to evaluate the intuitiveness of the system.

6. Results

6.1 Usability results

Effectiveness The brief introduction about the system proved to be insufficient for the children to grasp its purpose and usage. Multiple demonstrations were required before they were successful at using the system. This could be ascribed to a number of reasons. Firstly, the symbols on top of the blocks were not intuitive; the testees did not understand them without assistance from the instructor. Secondly, the required orientation in which the blocks had to be placed onto the trays was not well understood. Thirdly, although the mechanical design of the system ensures that the block will fit squarely onto the tray, it was not clear to the testees which side should face up. Fourthly, there was some confusion regarding the orientation of the symbol and the resultant movement of the toy robot. An explanation could be that the symbol represents the movement relative to the toy robot's own co-ordinates, but the testees expected the movement to be relative to the room's co-ordinates. After the first testee had finished the test, the subsequent testees who had observed the first were more successful in completing their tasks [13].

Efficiency The first testee spent close to 15 minutes mastering the use of the system to a sufficient degree to complete the set task. The second and third testees, who had observed the first, showed an average improvement of 60% in completing the task [13].

Satisfaction Feedback received from the testees indicates that they had enjoyed the challenge and the ability to control a toy robot. Some changes were recommended: the movements made by the robot were not visible enough and could be accentuated; colour-coding of the symbols would be useful (the cubes were already colour-coded); the movement directions represented by the symbols should be relative to the room and not the dynamic computational style as described in [5, p55] (for instance, if the symbol indicates a movement in the direction of a window in the room; the toy robot should move in that direction); smaller blocks would be preferred; the mechanical reliability of the concept demonstrator was lacking, resulting in unreliable operation; the speech produced by the toy robot was inaudible [13].

6.2 Educational results

In all tests the testees were eventually able to correctly sequence the blocks onto the trays according to the pseudo-code. In one test the first testee placed the blocks onto the trays in a random fashion, seemingly unaware that it had to be done according to the pseudo-code. This testee managed to correct the sequence after intervention by the instructor.

All testees were able to volunteer plausible mechanisms regarding the communication method employed between the system and the toy robot. Through conducting interactive group discussions with the testees, we elicited from them the method the system communicated with the toy robot, eventually correctly concluding that the actual method was infra-red emission [13].

7. Conclusions

Our goal was to design a Physical User Interface (PUI) to explore alternative ways to introduce young illiterate children to the art and science of computer programming in developing countries where informal exposure to computer programming is not readily available. It is hoped that this interface would also address the declining physical activity of those children who have unchecked access to modern recreational computer-based games. By requiring physical movement of the whole body when using the PUI, and not just the fingers, GameBlocks has the potential to also appeal to illiterate pre-school children whose fine motor skills are still developing.

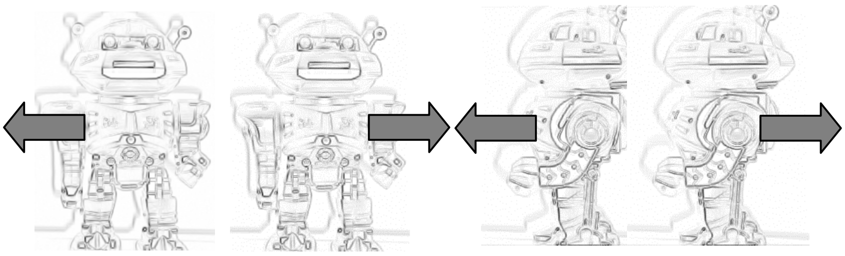
We reported on the usability and educational value of a novel affordable physical programming system. This was achieved without the use of an expensive computer. Tests indicate that significant learning is required for a novice user of the current GameBlocks implementation. However, all testees were able to order the instructions sequentially and interpret the symbols on the blocks to match the instructions and then place the blocks in the correct sequence onto the trays. We observed that learning did not take place primarily as a result of self-confident exploration or the intuitive-ness of the design, but rather mostly because of the interventions made by the facilitator. This new type of game was successful in creating great excitement amongst the testees, but the disadvantage was the uncertainty exhibited by them and the subsequent prolonged learning timeline.

We believe that our system also addresses the challenge of introducing a novice to the lower-level of abstraction [16, p70] as it relates to computer programming because there is a one-to-one correlation between the instructions and the resulting movement of the toy robot.

Similar to the aims of others when setting up a learning environment for using computers [17, p 43], our system-design facilitates movement and action around the blocks, reinforcing communication and information sharing amongst the children using it.

7.1 Recommendations

Firstly, the co-ordinates used by the toy robot could be made more explicit by improving the symbology used on the blocks (Figure 12). This would potentially resolve the confusion experienced by the testees who assumed room co-ordinates in their thinking processes when in fact the toy robot used its own co-ordinates when executing instructions [13]. Secondly, a mechanical linking mechanism between the blocks could be introduced to make sequencing more obvious to the first-time user (Figure 13). Thirdly, adding distinct markings on the front and bottom of the cubes could help overcome the problem with orientation that some testees experienced.



(a) (b) (c) (d)

Figure 12. Proposed improved block symbology, based on [13]. (a)Move to the left. (b)Move to the right. (c)Move forwards. (d)Move backwards.

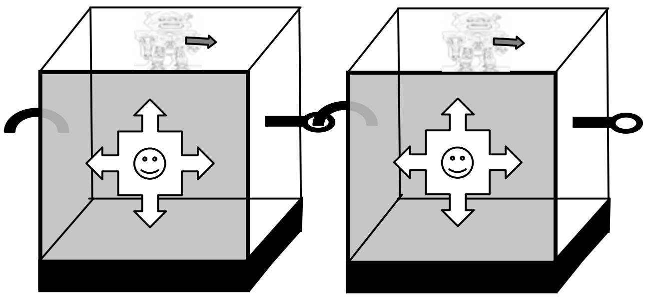


Figure 13. Proposed improved mechanical orientation mechanism, based on [13].

7.2 Future research

Further research is required for the development of an appropriate physical and visual syntax to represent more complex coding structures. Extended formal tests on pre-selected participants are needed to determine at which developmental stage the child will benefit the most from a system of this kind.

Tests with cubes of various sizes should be conducted to confirm the most age-appropriate block configuration.

Future research will explore the use of physical artefacts that are well-known to the target group, that is, children in developing countries. As an example, instead of using synthetic materials such as acrylic in the current system, wooden blocks carved by local craftspeople could be utilised. This idea is supported by [2, p3] where the author states that "A particular educational principle can well be transferred to another setting but it should be modified to accommodate the new cultural setting." (emphasis added).

7.3 Commercialisation

A number of issues have to be resolved before the GameBlocks system can be commercialised. These include the optimisation of the electronic circuit design, determining the optimal target market, developing clear symbology for the blocks, expanding the current instruction set, and using a child-appropriate material for the blocks.

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