Quantifying the visual perception skills of pre-school testees using a novel tangible electronic test instrument

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Abstract

Earlier studies discovered that South African testees from community schools do not have the required skills to participate in tertiary education and also lack many of the basic skills to compete successfully in certain sectors of society. These children were found to be less proficient in visualisation skills than their suburban counterparts. A new study was undertaken to ascertain whether there is any difference in cognitive skills, particularly visual perception, between pre-school children from the different socio-economic backgrounds (township and suburban). We state and elaborate on the reasons for choosing this specific age group. The ultimate aim of the study was to ascertain the age at which cognitive skill levels of these groups begin to differ and to develop intervention tools in the form of Tangible User Interfaces (TUI) to assist in enhancing the skills of the less advantaged children so that they can meaningfully participate in their own education. In this study we designed and evaluated an assessment instrument that directly measures pre-school children's visual perception skills that form part of literacy skills, as defined in the Persona Object Model in order to provide information that could contribute to the design of appropriate game-based learning tools.

Consequently, an electronic game-based tangible assessment tool, which measures the children's visual perception skills, was developed. This testing instrument was designed to take into account the limited cognitive- and fine-motor skills of the targeted age group. A number of tangible user interfaces were developed to address these limitations. We explain how the information and communications technology (ICT) used in the design of the test instrument allows for the automatic capture of the test data. The various design iterations of the test instrument are explained and motivated, which include the choice of microprocessor technologies and the invention of various custom designed TUIs. The paper also describes the abilities and issues that were identified during other practical intervention sessions held with pre-school children. Therefore, the paper reports on the design, testing and use of this instrument, in order to quantify the visual perception skills of pre-school testees. We conclude with recommendations for further development of the assessment tool.

1. Introduction

1.1 The context

It was discovered that testees from previously disadvantaged schools do not have the necessary skills to participate in tertiary education and lack many of the basic skills to compete successfully in certain sectors of society (Foko and Amory, 2005 & Foko, 2006). After 12 years of primary and high school education, many testees enter tertiary institutions lacking visual, logical, numerical, reading and writing skills. These are the skills testees need to perform at a high level in tertiary schools. Cultural norms and background including gender, race, socio-economics, access and curriculum are major factors involved in poor performance (Blunch, 2002 & Luckett, 1995).

What is discomforting is a lack of understanding whether children start primary school education already lacking these skills. It is because of this concern that a new study was undertaken to ascertain whether there is any difference in cognitive skills, particularly visual skills (perception and orientation), between pre-school children from the different socio-economic backgrounds (township and suburban). The question is whether these skills are nurtured at an early age because children are born inquisitive, energetic, passionate, motivated, creative, risk taking, and 'experiential' (Peel and Prinsloo, 2001). The environment has a big influence, positive or negative on these learning skills.

The Persona Outlining Model (POM) (Figure 2), which is based on the Game Object Model (GOM) (Figure 1), is used to describe a typical game player or target audience in terms of the abstract interfaces of the GOM visualisation space, the concrete interfaces of the problem space and a number of properties (Amory, 2001 & Amory and Seagram, 2003). One of the objectives of this research was to design and test an assessment instrument that directly measures many of the concrete interfaces of the POM literacy space (visual and logical). Thus, a typical pre-school learner's visual skills will be determined using the POM.

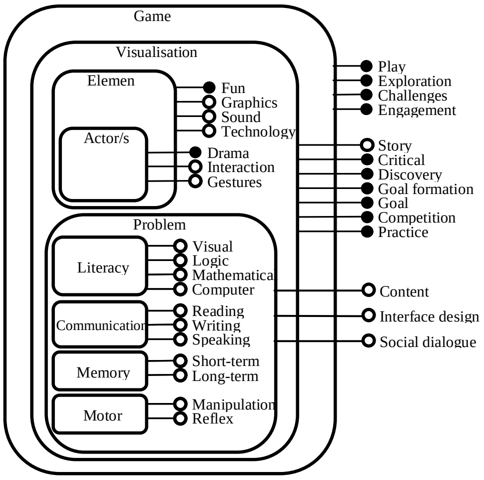

Figure 1: Visualisation of the Game Object Model (from Foko, 2006)

The results presented here are those of a pilot test that was carried out in two schools in the Gauteng province. The schools provide a similar curriculum even though they cater for two different demographics. School A is based in Pretoria and caters for children from middle class families and School B is in Putfontein and caters for testees from the previously disadvantaged communities and lower middle class families in the area.

The studies carried out by Foko and Amory (2005) and Foko (2006) clearly indicate that high school testees who lack visual skills do struggle at tertiary level. Other studies reveal that children from poor families are at risk for cognitive delays and poor performance at school (Smith, Brooks-Gunn and Klebanov, 1997). The authors believe that some of the skills that impact learning at tertiary levels are a product of a schooling system and lack of opportunities for certain people irrespective of their colour, race or creed, and testees are not born already lacking these skills. As a result, we carried out a research activity whereby we studied the visual abilities of pre-school children from two different cultural and socio-economic backgrounds with the common denominator being the same curriculum. We tested the visual skills of the testees and asked testees to control a toy robot through very basic programming using a TUI.

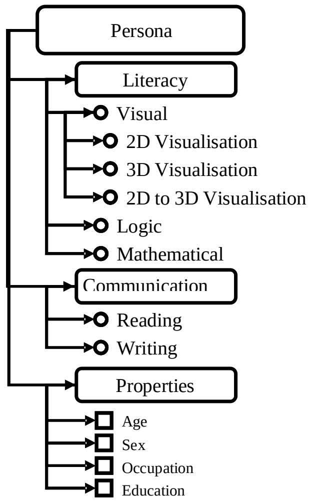

Figure 2: The Persona Outlining Model (from Seagram & Amory, 2003)

1.2 Importance and impact of visual skills in learning

This paper focuses mainly on usage of visual skills to perform basic programming using RockBlocks (Smith 2008a). For the purpose of this paper visual skills will include the different categories of visual ability, which are visual perception, mental rotation and visualisation as classified by Contreras and colleagues (2003). Linn and Pertersen (1985) assert that this "ability generally refers to skill in representing, transforming, generating, and recalling symbolic, non-linguistic information". Therefore, visual skills tests measure the ability of individuals to mentally manipulate material that is present in space and it could be in the form of one, two or three dimensions. For children to be comfortable and willing to engage and explore there is a need to introduce into their environment from an early age positive science and ICT. Hence, it is important for children to develop their visual literacy skills from an early age so that they can cope with future educational endeavour and life in general (Foko & Amory, 2005 and Foko, 2006).

1.3 Constructivism

Contemporary learning practices emphasise the use of a constructivism paradigm that is closely aligned with the theories of Piaget, Bruner and Vygotsky (Butts & Brown, 1989; Kim, 2001). Piaget states that learning involves individual constructions of knowledge and describes learning as occurring through interactions with one's environment. Vygotsky's social constructivism views learning as a social construct mediated by language *via* social discourse, stressing the primary role of communication and social life in meaning formation and cognition (Boudourides, 2003) and emphasises learner's co-construction of knowledge (Taylor *et al.*, 1997). Learning is therefore not about shaping of behaviours but about a transformation of individual views that then transform the world.

1.4 Research framework

The study is guided by the design experiment/development research paradigm, which according to Reeves (2000) calls for a "pragmatic epistemology that regards learning theory as being collaboratively shaped by researchers and practitioners" with the overall goal of solving real problems while simultaneously constructing "design principles which can inform future decisions". A fundamental tenet of development research is collaboration among practitioners, researchers and technologists and should be tailor-made for the needs of each situation.

1.5 Practical issues when conducting tests with pre-school children

The following were taken into consideration when this pilot was conducted. We want to emphasise that this section reports on personal experience.

1.5.1 Emotional

Positive emotional behaviour in the classroom is necessary to ensure positive outcomes of the intervention.

Children enjoy the activities more if they are able to complete the task at hand. Some children become frustrated if they take longer than their peers to complete the task. Pre-school children need significant encouragement and recognition to build their self-confidence and the belief that they can complete a task. Children need guidance when a problem is encountered.

1.5.2 Thinking (concrete to abstract)

Children have difficulty in transforming concrete objects to paper drawings. For example, some children stated that they could not draw because the paper was too small.

1.5.3 Senses

Children are not interested in listening to long explanations but want to start with the activity at hand as soon as possible. It is easier for children to listen if the content includes visual material.

1.5.4 Physical skills

Children of this age group struggle with activities involving fine- and gross-motor skills as these are still developing. An example is tying a knot.

1.5.5 Focus

Another lesson learned is the necessity to pay attention to the task the children needed to complete. It was found that too much equipment tended to distract them.

1.5.6 Numbers and visual orientation

Almost all the children are able to recognise the digits '1' to '5' with ease but struggle with numbers larger than five. Some children have difficulty to distinguish between the digits '2' and '5' and confuse the orientation of '2', '5' and '3'.

Metric units of measurement have little meaning to these children. The children measure in physical quantities by comparing sizes. Examples of this are 'larger'/ 'smaller', 'taller'/ 'shorter'. Another example is measuring the strength of a bridge by counting how many apples it can carry before it breaks.

1.5.7 Discipline

Seeing new faces may lead to discipline becoming a problem because of the excitement the group experiences. The presence of a school teacher during the intervention provides the required level of discipline.

1.5.8 Interaction

Arranging the classroom in such a way that all children can see and participate, results in a positive learning environment for the presenter and children. Children who cannot see the activities lose interest.

Not all the children are equally interested in all activities, but the fear that they might be missing out on something encourages them to continue with the task at hand.

An intervention should not last longer than one hour.

Large groups are difficult to work with because of the amount of assistance pre-school children need. A single presenter can easily manage a group of six children.

2. Electronic test system

The various design iterations of the tangible electronic test environment all make use of the simple and low-cost technology found in most South African homes. This technology is the magnetic door- and window-sensors used in alarm systems. Magnets are inserted in tangible objects (Figure 3) and corresponding magnetic sensors are placed inside multiple sensing surfaces (Figure 4). Custom-designed electronic circuitry interrogates the sensors to detect when and what configuration of magnets have been placed on top of which sensing surface. This information is then interpreted by the electronic circuit and the result sent in the form of an infra-red command to a roaming toy car (Figure 5). The toy car responds with a pre-determined sequence of movements which corresponds to the received instruction. In the tests described here we made use of a novel programming environment called RockBlocks (SMITH 2008a).

Figure 3: Four of the rocks used in the experiments. These were the only rocks used in Part 1 of the tests. (From left to right they are: Rock 1, Rock 3, Rock 2, and Rock 4).

Figure 4: Four wooden programming squares used in the tests. The squares are interpreted from left to right.

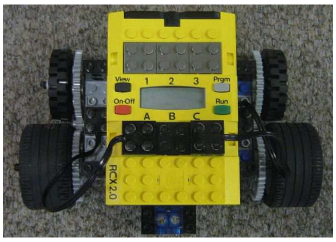

Figure 5: Motorised toy car used in the experiments.

2.1 Design iterations

We went through three design iterations for the TUIs. The initial version (Smith 2006) was designed to give children insight to the technology used by using transparent materials for the enclosures. It consisted of large, transparent acrylic cubes containing magnets on one of the inside surfaces. The cubes were then placed on a reading surface containing magnetic sensors. This version was not designed to automatically capture research data.

The second iteration consisted of soft, commercially available synthetic foam squares formed into a cube (Smith 2008b). Like the first iteration, magnets were embedded onto the inside surface of one of the cube sides (Figure 6). The programming surface was now also constructed using the same foam squares as used for making the foam cubes. This iteration makes use of an infrared communication channel to control the moving car, allowing for the automatic capture of data.

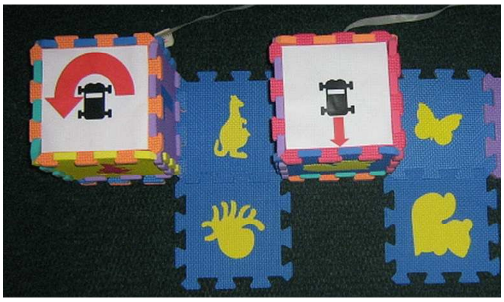

Figure 6: Tangible user interfaces in the form of foam cubes.

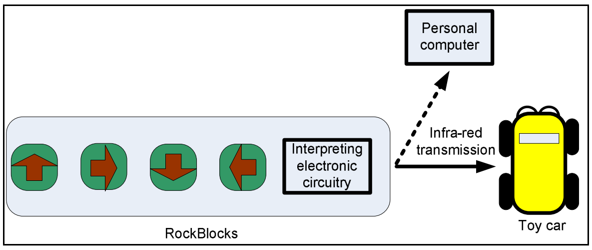

Figure 7: Configuration for automated data capture.

The current iteration incorporates natural materials such as rock and wood (Figure 3). Rocks have been shaped into roughly-formed triangles with the intent of showing direction. The rocks were then mounted onto a wooden base into which magnets had been embedded. In this iteration, the programming surfaces consist of wooden squares (Figure 4) containing the embedded magnetic sensors (Smith 2008a).

All the design iterations make use of low-cost and simple electronic circuitry. These properties make the TUIs especially well-suited for developing countries with limited infrastructure. This is because a person with limited knowledge of electronic circuitry will be capable of constructing and maintaining the TUI.

2.2 Automatic data capture

Both the second and current iterations have the option of automatic data capturing. This can be done using a custom-designed computer application. Automatic data capture is possible because of the infrared communication channel used to send instructions from the main electronic unit to the roving toy car. Each message sent along this channel uniquely represents the orientation of the tangible objects. Messages are sent at four-second intervals, one per sensing surface, starting from the left-most surface. The capturing application simply eave-drops onto this channel. It then logs the instructions for later analysis (Figure 7). The infrared channel provides a one-to-one representation of the tangible objects placement on the sensing surfaces. Once the test has been completed the captured data is available for analysis. Automated data capture eliminates possible human error when a large number of data points have to be collected.

3. Test methodology

3.1 Participants

In this preliminary research, three researchers visited two Montessori pre-schools, one in Pretoria East (School A) and another in Putfontein (School B). In the first preliminary study conducted at School A, 10 pre-schoolers between the ages of five and six participated. Although ethnicity was not a criterion for taking part in the study, there were eight white children (six boys and two girls) and two blacks (one boy and one girl). These children were mainly from middle class families with an average age of 5.75 years. School B pupils who took part in the study were all black with six boys and 11 girls who averaged 5.47 years of age and came from lower income families in townships in Daveyton and Springs.

3.2 Materials

There are a number of activities pre-schoolers were required to do in this study. Each activity involved usage of a number of tools. This study used crude pentagon- and triangle-shaped rocks with at least one section cut to form an arrow edge to indicate the direction (Figure 3). The study also used colourful foam squares as a surface for a toy car to move on (Figure 8). A toy car moves on the mat as per the programming directions given by testees in the way they align the rocks on the wooden programming squares (Figure 4).

Figure 8: Controlling a toy car using RockBlocks. Here the testee has placed one rock on a programming square (right) to control the toy car (left).

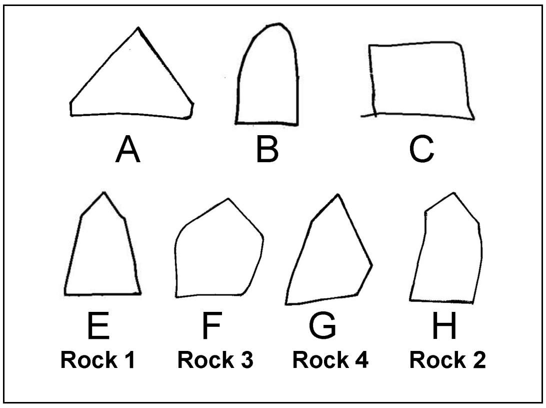

Figure 9: 2D Line drawings of rocks. Drawings in the top row do not represent any of the rocks used in the tests. Drawings in the bottom row represent the four rocks used in the tests.

Therefore, this study involves three simple visual skills activities. The first study deals with matching 3D objects to 2D drawings. The second activity is where testees match the directions of the rocks to those drawn on the paper. The third activity involves testees attempting to control a toy car through programming using RockBlocks.

3.3 Procedures

All the activities were individually done by the pre-school testees. However, before testees could start any activity, researchers explained to all the testees as a group what was expected from them. When testees commenced with their individual activities researchers again explained extensively how they should go about their tasks to avoid confusion about what they had to do as they still lacked the skills for reading instructions and could not refer to written instructions.

3.3.1 Part 1 – Matching 3D to 2D objects

The first literacy test based on POM dealt with matching 3D objects to 2D drawings. In this test four line drawings of four tangible rocks were made on paper (Figure 9, bottom). Three different 2D line-drawings, which did not resemble any of the rocks, were also used (Figure 9, top). From these drawings four questions were designed where testees were instructed to match rocks (Figure 3) to these 2D drawings. Each question had four choices with only one correct answer. The correct answer was mixed with the three drawings that did not resemble any of the rocks.

Testees worked individually and only one learner was allowed to enter the testing room at a time.

3.3.2 Part 2 – Matching directions of rocks with arrows drawn on paper

In the second POM based literacy test, testees had to identify the directions of the rocks. Eight sheets of paper with one arrow drawn (Figure 10) on each were placed on the floor and testees had to match the directions on the rocks with those on the paper.

For this activity again only one learner was allowed to enter the test room at a time in order to match the objects. Testees worked individually to match the rocks directions with the arrows drawn on paper (Figure 11).

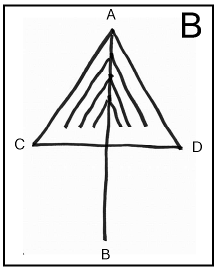

Figure 10: Hand-drawn arrow on a sheet of paper used to test orientation skills. Each sheet of paper was marked to aid later analysis of the test results. Lettering has been added to support the discussion in this document and is not part of the arrow.

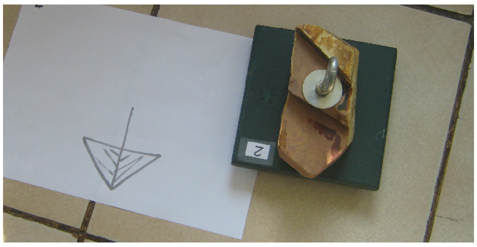

Figure 11: Example of a rock (Rock 2) oriented to match the direction of an arrow drawn on paper.

3.3.3 Part 3 – Programming with RockBlocks

The third literacy test based on the POM required the testee to place rocks (Figure 3) onto programming squares (Figure 4) to control the movement of a toy robot car (Figure 5). By changing the orientation of the rock on the programming square, the direction and movement of the toy car can be controlled. For each car movement, the testee would decide in which direction the car should move and place a rock in the corresponding direction onto the programming square. Up to eight instruction sequences could be programmed in this way. Once the testee was satisfied with the sequence of instructions, she would activate the system by depressing a switch. The instructions are then sent to the car for execution.

4. Test results and reflections

4.1 Part 1—Aligning 3D to 2D objects

In this test the testees were instructed to align four 3D blocks (Figure 3) to four 2D figures. The average performance of testees from the two schools was 40,38%. This test consisted of four questions. Testees from School A, where 10 testees participated, attained an overall score of 73% with only one learner not obtaining 50% or better. Five of these 10 testees obtained a score of 100%. Testees from School B had the average score of 20% with the highest testees obtaining a score of 75%.

Question 1

In this test the correct answer was drawing ‘E’ in Figure 9. Testees from School A attained a mean mark of 60% compared to 6,25% of School B. School A testees who got this question wrong were confusing Rock 2, Rock 1 (Figure 3) and drawing ‘A’ instead of realising that Rock 1 was very small and Rock 2 was big while drawing ‘A’ had a big triangle (arrow edge) at the top and long base compared to the blocks. And 75% of School B testees confused Rock 1 with drawing ‘A’.

Question 2

In this test the correct answer was drawing ‘F’ in Figure 9. 90% of the testees from School A, and 31% of School B identified the correct drawing. Only 10 of the testees from School A confused Rocks 1 and 3, even though one rock is big and another rock is small in size, which are easily discernable, even from the drawings. Furthermore, 38% more testees from School B chose the incorrect answer (drawing ‘SAICSIT B’) and confused Rock 2 with drawing ‘B’.

Question 3

In this test the correct answer was drawing ‘G’ in Figure 9. 80% of testees from School A chose the correct answer. Testees confused a pentagon-shaped rock (Rock 2) with a rectangle (drawing ‘C’). Only 25% of the testees from School B chose the correct answer. They seemed to be guessing the answer.

Question 4

In this test the correct answer was drawing ‘H’ in Figure 9. 37,5% of the testees from School B chose the correct answer compared to 60% for the testees from School A. Testees from School A who got this question wrong were confusing Rock 1, Rock 3 and Rock 4. Rock 1 is very small and Rock 2 is big while Rock 4, although small, is very irregular compared to the other two. Again the different answers from School B testees indicate that they were guessing their answer.

4.2 Part 2 — Matching directions of rocks with arrows drawn on paper

In this exercise testees were instructed to match eight rocks (including those in Figure 3) with arrows drawn on sheets of paper (Figure 10). The aim of this exercise was to ensure that all the testees had the same understanding when they performed Part 3 of the tests.

For this exercise, with an overall score of 93,75%, 80% of testees from School A were able to match all the directions. However, two testees did not try to match the directions of rocks with the directions drawn on paper but instead matched the numbers on the rocks to those on paper. This came as a surprise to the researchers because, although it happened almost towards the end of the exercise, it caused some confusion as to the reason why only two out of 10 testees decided to match the numbers. This happened even though instructions were given repeatedly. It is therefore important when working with children to ensure that they do understand at all times what is required of them.

For this part testees from School B attained the overall score of 80,15% with nine out of 17 testees scoring 100%. Again, two testees tried to match the numbers on the rocks with those on the paper. Another problem discovered was that some of the School B pre-schoolers have a poor understanding of an arrow as a concept and therefore could not apply its use in relation to directions. This made it difficult for some testees to understand what was required of them even though explanations were extensively provided. This led to a situation whereby some testees guessed their answers.

4.3 Part 3 — Programming with RockBlocks

This exercise involved navigating a car from one square to another square (Figure 12). Hence it was important that testees understood that the game environment was based on moving from one predefined position to the next by using a combination of four movements (turn left, turn right, move forward and move backwards). This could be done by rotating rocks (Figure 3) in the correct orientation and placing them on the programming wooden squares (Figure 4).

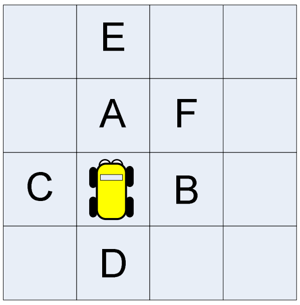

Figure 12: Physical configuration for testing programming using RockBlocks. The letters have been added for the purpose of this document and were not present during the execution of the tests. The car is shown in the starting position.

The study was unintentionally divided into two parts (Part 3a and Part 3b). In Part 3a the testees attempted to do simple motions by placing rocks on the wooden programming squares in such a way that the car would do simple manoeuvres like going forward (from the starting position to position A, Figure 12) or turn to the left (position C) or right (position B) or move backward (position D). It was important for the testees to understand these four manoeuvres before they could attempt Part 3b of the study which involved testees, who had successfully completed Part 3a, to execute two or even three more step in a single attempt. For example, testees were asked to instruct the toy car, using the rocks, to move two blocks forward and turn either to the left or right.

90% of testees from School A and 85% of School B were able to perform the tests in Part 3a successfully. Directing the car to move backward was a problem to most testees from both schools. Although 60% of testees from both test groups managed to programme their car to do the reverse manoeuvre, 20% of School A and 27% of School B testees did so after having received significant assistance from the researchers.

Although most testees from School A qualified to proceed to Part 3b, only four testees were requested to do so due to time constraints. In Part 3b, testees were instructed to move the car two squares forward (Figure 12, position E) and turn it to the right. Three out of four testees were able to position rocks in such a way that their car moved forward two squares successfully. From the three testees only one, with some assistance, was able to position the rocks in such a way that the car would turn and move forward. Another testee could only programme the car to turn but was not able to get it to move forward instead the car immediately turned to the right.

Part 3b of this activity was attempted by nine testees from School B with only three managing to programme the car to move four blocks. These testees, with little explanation from the researchers, were able to get the car to move forward and turn right and move forward once again. They were very impressive. However, of the remaining six testees, four could programme their car to move forward only. They were unable to instruct the car to first turn and then move one square forward. The other two testees seemed to have a 'mental block when they were asked to attempt moving their car two blocks and turning it.

Figures 13 and 14 graphically indicate the visual and programming-skills performance of the two test groups.

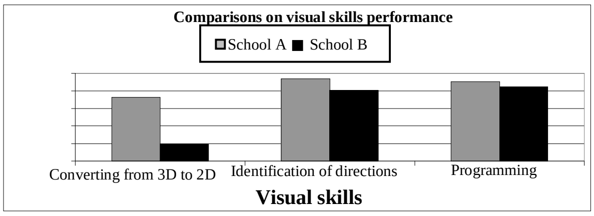

Figure 13: Performance results for the various visual skills tests.

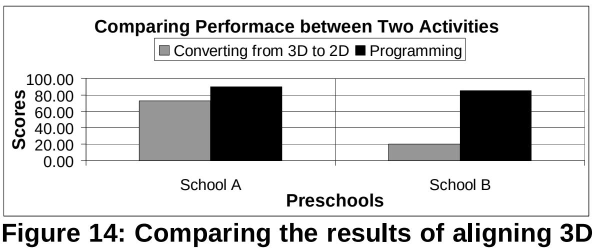

Figure 14: Comparing the results of aligning 3D objects to 2D drawings and RockBlocks programming.

The results in Figure 14 indicate that although learners from School B did not perform well when converting 3D to 2D objects, by the time they started their programming activities they had understood what was needed of them; hence the higher results for programming.

5. Reflection and discussion

The findings of this preliminary study illustrate that for testees to be able to programme properly using the RockBlocks, they need to have good understanding of direction and visual perception skills. It was however discovered that these skills were not so well developed in the pre-schoolers. This was seen when many pre-schoolers, particularly those from School B, could not match the 3D rocks to 2D objects. Foko (2006) had contended that rural and township testees performed poorly because of the poor quality of education they received and their poor home economic status. In this particular case we have two pre-school groups in environments that use the same international schooling system and the testees are of the same age. However, we found that the pre-schoolers who came from the townships and whose first language is not English performed badly compared to their more affluent counterparts attending School A. The results are similar to those attained by Grade 11 and 12 scholars and university students who came from similar demographics (Foko and Amory, 2005; and Foko, 2006). Foko (2006) in his thesis concluded that township and rural schools do not provide children with good visualisation skills. This has now also been observed in five- and six year-olds. Testees from School B struggled to match the directions of rocks with arrows drawn on paper. This we conclude was because most of these School B testees did not comprehend the relationship an arrow has with direction. For example, some interpreted the tail of the arrow as indicating the direction (Figure 10, direction of the line AB). Some of them tried to explain the meaning of the arrow in relation to the arrows often found in traffic light clusters. Unfortunately, these young testees had not yet mastered language sufficiently. This made it difficult for them to verbalise their thoughts properly. Still these testees also insisted in communicating in English, a language that was still mostly foreign to them.

As for programming using RockBlocks, we found that the performance gap was narrower between the schools than in changing the 3D to 2D objects and both groups performed equally well. Once the testees understood the meanings of the arrows and how directions are determined, their performance improved. This includes testees from School B. Programming activity results of the School B testees show a dramatic improvement when compared to the task results of converting 3D objects to 2D objects.

6. Conclusions and recommendations

We have described an electronic system to aid in testing the visual perception skills of pre-school children. The iterations through which the system has evolved were given, each iteration reducing the cost of the tangible user interface. However, a component of the system that has not received sufficient attention to reduce its cost significantly is the output device. The current output device is made from a commercial toy designed in Europe to what is arguably a too high standard for the local need in a developing country, resulting in system costs that are potentially unaffordable to those in need of an evaluation system.

In our tests with pre-school children, we have identified a problem with the mechanical design of the programming user interface: placing the rocks properly onto the tray is a problem. One solution could be the addition of keying mechanism to automatically align the wood-mounted rock with the wooden reader-tray.

Test results show that, whether testees come from the poor townships or from the rich suburban areas, it is easier for them to programme with RockBlocks if their visual skills have been developed appropriately. The study found that, regardless of the background of testees, RockBlocks is potentially a tool for measuring visual perception skills among pre-school children.

Finally and more importantly, because of the small sample of testees who participated in the POM literacy test (visual ability test) there is a need for more research to be carried out. For conclusive findings on the visual abilities of pre-school learners more schools across the socio-economic spectrum of the country need to participate in the subsequent study.

7. References

AMORY, A., 2001. Building an Educational Adventure Game: Theory, design, and lessons. Journal of Interactive Learning Research. 12 (2/3), 245 – 264.

AMORY, A., and SEAGRAM, R., 2003. Education Games models: conceptualisation and evaluation. South African Journal of Higher Education. 17(2), 206 – 217.

BLUNCH, N., 2002. Determinants of Adult Literacy and Numeracy Skills in Ghana. The George Washington University: Department of Economics.

BOUNDOURIDES, M.A., 2003. Constructivism, Education, Science, and Technology. Canadian Journal of Learning and Technology. 29(3) Fall/automne.

BUTTS, R.E. and BROWN, J.R., eds., 1989. Constructivism and Science. Norwell, MA: Kluwer Academic Publishers.

CONTRERAS, M.J, COLOM, R., HERNANDEZ, J. M. and SANTACREU, J. 2003. Is static spatial performance distinguishable from dynamic spatial performance? A latent-variable analysis. Journal of General Psychology, July, 2003.

FOKO, T., & AMORY, A. 2005. Playing Computer Games in Education: Development and use of an assessment tool to measure player skills prior to ame Play. Special issue: ICT in Education – Education as Change 2005 (2), 24-45.

FOKO. T. 2006. The Role of Computer Games and Social Constructivism in Skills Development of Learners from the Disadvantaged Backgrounds. PhD Dissertation. University of KwaZulu Natal.

KIM, B., 2001. Social constructivism. In M. Orey. ed., Emerging perspectives on learning, teaching, and technology. Available online: http://www.coe.uga.edu/epltt/SocialConstructivism.htm

JONE, J. and BURNETTE, G. 2007. Spatial Skills and Navigation of Source Code. ACM New York, NY, USA.

LINN, M.C. and PETERSEN, A.C. 1985. Emergence and Characterization of Sex Differences in Spatial Ability: A Meta-Analysis. Child Development, 56, 1479-1498.

PEEL, S. and PRINSLOO, F. 2001. Neuro-Integration Movements Workshop: Module 1. Brain Gym Edu-K South Africa.

REEVES, T.C., 2000. Enhancing the Worth of Instructional Technology Research through "Design Experiments" and Other Development Research Strategies. Conference on International Perspectives on Instructional Technology Research for the 21st Century. New Orleans, LA, USA.

SMITH, J.R., BROOKS-GUNN, J., and KlEBANOV, P.K. 1997. Consequences of living in poverty for young children's cognitive and verabal ability and early school achievement. In G.J. Duncan & J. Brooks-Gunn (Eds), The consequences of growing up poor (pp.132-189). New York: Russell Sage Foundation.

SMITH, A.C., 2006. Tangible Cubes as Programming Objects; Artificial Reality and Telexistence: 16th international conference. California: IEEE Computer Society.

SMITH, A.C., 2008b. A Low-cost, Low-energy Tangible Programming System for Illiterates in Developing Regions. Technology for Innovation and Education in Developing Countries. Uganda.

SMITH, A.C., 2008a. Handcrafted physical syntax elements for illetterate children: initial concepts. Interaction design and children. Chicago: ACM.

TAYLOR, P., GEELAN, D., FOX, B. and HERRMANN, A., 1997. Perspectives and Possibilities: Electronic Interactivity and Social Constructivist Teaching in a Science, Mathematics and Technology Teacher Education Program. In What works and why? Proceedings of the Australian Society for Computers in Learning in Tertiary Education (ASCILITE) Conference, Curtin University.

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