USING AN INTERACTIVE SIMULATION TO ENHANCE PROCEDURAL SKILLS IN GRADE 5

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ABSTRACT

The discrepancy between what we teach and what scientists and citizens need is greater than most instructors realise. Science for citizenship and science in the technical workplace, both involve greater emphasis on procedural understanding than on understanding of concepts. In this paper, we explore the possibility of guiding upper elementary school students to develop procedural skills in close connection with conceptual understanding through a structured intervention on designing experiments. After implementation, the learning outcomes were assessed and further developed using an interactive database program developed by the University of Durham. The paper presents the design of our intervention, the structure of the software application and the learning outcomes. We also present conceptual and reasoning difficulties encountered by students in their effort to construct a coherent and consistent strategy for designing valid experiments. Finally, we discuss implications of our findings for the design and development of science curriculum for the elementary grades.

KEYWORDS

Procedural understanding, control of variables, simulations

INTRODUCTION

The discrepancy between what we teach and what scientists and citizens need is greater than most educational systems are willing to admit. Science for citizenship and science in the technical workplace, both involve greater emphasis on procedural understanding than on understanding of concepts. Our efforts to develop either are commonly undermined by student tendency to bypass the learning process through, for instance, rote memorization. Despite extensive research in science education over recent decades, we have yet to witness serious breakthroughs in teaching and learning processes on a wide scale. Furthermore, most research has tended to address issues related to the development of student conceptual understanding in science, with relatively little work done on student mastery and application of procedural skills.

In science teaching and learning, designing experiments is an important procedural skill. In many science programs, children are expected to undertake investigations, formulate questions, design and perform experiments. Designing experiments involves two reasoning skills: identification and control of variables.

Assuming that the control of variables skill is an essential scientific skill and evaluating the results of previous research, which proved that very few children spontaneously apply the control of variables strategy when they design an experiment, it is important to investigate whether there are fruitful teaching methods to help children acquire this fundamental scientific skill (Chen & Klahr, 1999).

This paper relates to an ongoing project to investigate student ability to identify and control variables in multiple contexts, and examines the level of transfer of these skills to the design of controlled experiments.

BACKGROUND

Children often come up with questions in science lessons that can lead to investigative work. In many science classrooms, activities on designing a fair test or organizing a valid experiment in order to answer a given investigable question are commonplace. In order to investigate, for instance, whether the mass of a ball affects the time it needs to roll down a ramp, when released from the top of the ramp, a child must

- recognise that the investigable question is *"Does the mass of a ball affect the time it needs to roll down a ramp?"* ,
- identify the two variables involved in the investigable question, the *mass* of the ball and the *time of flight*,
- control variables, which means that, in every measurement, the variable that has to be changed is the mass of the ball (independent variable), the variable that has to be measured is the time of flight (dependent variable), and all other variables (e.g. the volume of each ball, the surface of the ramp) that might possibly affect the time of flight need to kept constant.

When the above procedure is followed in a systematic way, we assume that the child has designed a fair test or a controlled experiment, and the conclusion that derives from this experiment is also thought to be valid.

The ability to design controlled experiments and make valid inferences from their outcomes are basic procedural skills that have attracted a lot of attention both in science education and in cognitive psychology. The acquisition of the control of variables strategy is an important step in the development of scientific reasoning skills. In order to fully appreciate the importance of the control of variables strategy, one must take into consideration that, although this strategy is closely linked with the design of experiments in science contexts, it is also applied in different domains of science and everyday life and it underpins more complex abilities such as multiple causality, correlational dependencies, historical causality, and decision making on issues of public and private policy.

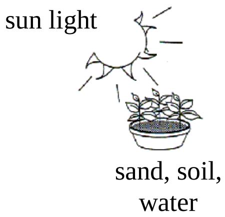
The Learning in Physics Group at the University of Cyprus has a co-ordinated program combining research with the development and validation of inquiry based curriculum. In one aspect of this program, we designed a series of lessons that aimed to guide fifth grade children to construct the concept of variable, to formulate investigable questions and relate experimental design to these questions, to design and critically evaluate experiments as to their validity, as well as to transfer the control of variables strategy to previously unfamiliar contexts. The context in which we based our curriculum was kinematics. Specifically, we engaged the children in an investigation of the variables that might affect the time of flight of a ball rolling down a ramp. Specially developed pre-tests and post-tests were administered before, during, and after the instruction. The tests provided valuable data for further refining the children's level of acquisition and transfer of the control of variables skill and evaluating the effectiveness of the curriculum.

Two tests that were used to evaluate children's ability to design controlled experiments after instruction are shown as Post-tests 1 and 2.

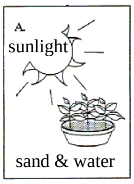
Post-test 1:

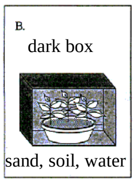
Tim believes that plants need sand in their pot to grow. He tested his belief performing the following experiment: he took a pot with a grown plant in it, added sand, soil and water, and placed it under direct sunlight (Picture 1).

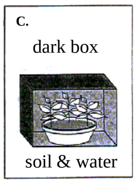
Picture 1

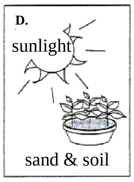


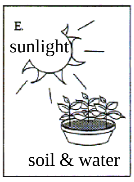
Which of the following experiments will he also perform in order to decide whether plants need sand for growth? (circle the correct answer)











Answer the following questions:

1. What is Tim's investigable question? ..……………………..…………………………

2. According to Tim's investigable question,

- What variable has to be changed? ……………………………………..…...………..
- What variables have to be kept constant? ...……………………………………………
- What variable has to be measured? …...……………………..………………………

Modified from TIMMS REPEAT

Post-test 2:

George wanted to examine if the color of the wrapper of specific type of ice cream affects the time the ice cream needs to melt. In order to answer this question, he performed the following test:
He bought several ice creams with different colour wrappers, measured each ice cream's mass as it is shown in the table below and put all ice creams in the freezer. Afterwards, he took out of the freezer all ice creams at the same time, placed them all on his car's front dash board and measured the time each ice cream needed to melt.

	Ice cream flavor	Color of ice cream wrapper	Ice cream's mass	Melting time
1	Lemon	White	80 gr.	8 minutes
2	Lemon	Brown	80 gr.	8 minutes
3	Chocolate	Green	100 gr.	6 minutes
4	Chocolate	Yellow	120 gr.	9 minutes
5	Vanilla	Blue	120 gr.	11 minutes
6	Strawberry	Black	120 gr.	12 minutes

According to George's test and his measurements, can you say whether the color of the ice cream's wrapper affects the melting time?
……………………………………………………………………………………………………...

Explain your reasoning, mentioning which of the above measurements you used to reach your conclusion.
……………………………………………………………………………………………………...

Adapted from
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University of Washington, Seattle

Both Post-test 1 and Post-test 2 examine children's mastery and transfer of the control of variables strategy in contexts other than kinematics and provide useful evidence of children's understanding of the fairness of the experiment. The format of the question in Post-test 1 was familiar to the children, as it was based on a procedure they had worked on during the lessons, albeit in another context. Post-test 2 was a completely new type of task that they had not encountered before. It is reasonable to consider that Post-test 1 required near-transfer and Post-test 2 required far-transfer on the part of the children. Post-test 1 required the application of the control of variables strategy in order to select one out of five choices in experimental design. The questions at the end of the test provided additional help: children could go back to their selection and check whether it was consistent with their subsequent answers to these latter questions. Post-test 2 was more difficult for the children, because it also did not guide them through the reasoning underpinning the design of controlled experiments, and, as a result, it required the following mental steps:

a) isolation of the investigable question,
b) identification of the variables involved in the question,
c) identification of the variable that has to be changed, those that have to kept constant, and the one that has to be measured,
d) isolation of the measurements from the table that differ only in the values of the variable that has to be changed and perhaps the one that has to be measured, while all other variables are kept constant,
e) comparison between the values of the variable that is measured,

f) formulation of a conclusion, as to whether the examined variable affects or not the measured variable.

The analysis of children’s responses to these tests, as shown in Table I, provided variable results about their mastery and application of the control of variables strategy.

Table 1. Children’s rates of success in Post-test 1 and Post-test 2

	Correct response with correct reasoning	Correct response with inadequate reasoning	Incorrect response
Post-test 1	73 %	24 %	3 %
Post-test 2	0%	13 %	87 %

A typical answer given in Post-test 2 (“*The experiment is not fair, because all ice-creams ought to have the same mass*”) enabled us to identify the following difficulty; when faced with a series of measurements, children refused to select the ones that could validly be used to answer a question with the rationale that the experiment had not been designed correctly. In other words, the presence of additional, irrelevant measurements rendered an experiment invalid in the eyes of the children.

This paper evolved from our effort to respond to the following question: can an interactive database be used to guide students to overcome this difficulty?

METHOD

Participants

Thirty-three fifth graders participated in the present study. Their socioeconomic status was medium to high and, prior to our intervention, they were all able to use a computer confidently.

The curriculum that guided our intervention and the children’s work is part of an ongoing project known as *Science by Inquiry*, a program that seeks to promote reasoning skills, epistemological awareness, and the development of procedural and conceptual understanding in an integrated manner.

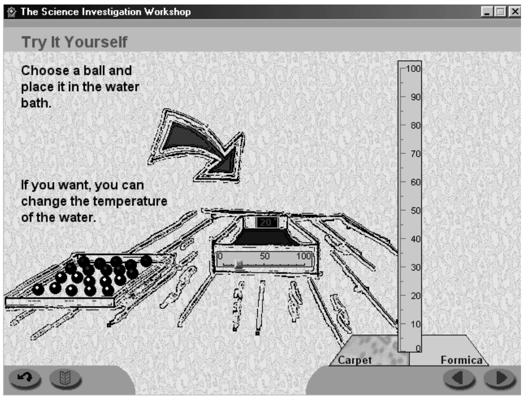
The teaching intervention

The teaching intervention took place at one of the computer laboratories of the University of Cyprus and the curriculum designed aimed at continuing the development of investigative skills. The main objectives of this part of the curriculum are detailed below. Children are expected to:

- develop the ability to identify and formulate investigable questions,
- identify the variables involved in a given situation and appreciate whether some of them are being controlled or not,
- design experiments that can lead to valid conclusions in relation to a given question,
- organize the collection and analysis of data in a systematic manner, purposefully targeted at answering a given question.

Children initially identified variables that might possibly affect the bouncing of *squash balls.* Children were then guided to design a valid experiment to test whether a particular variable actually influenced the bounce height. Hence, the children at this stage had to apply the control of variables strategy, that had been developed in previous lessons, in order to design a fair test. The main shortcoming that appeared in many proposed experimental designs concerned the measurement of the dependent variable. Children failed to find a way that would enable them to measure the exact rebound height of the squash ball. After this difficulty was revealed, the curriculum went on to present an interactive computer-based simulation package that could be used to make fast (virtual) measurements.

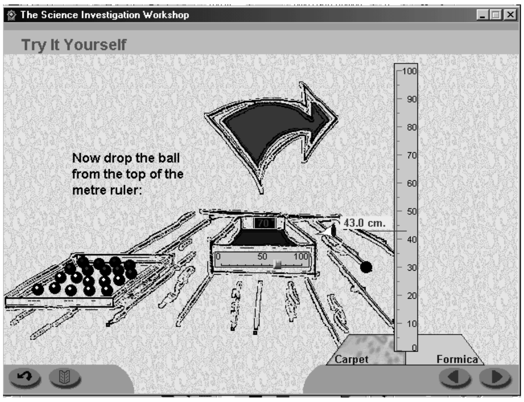
The interactive simulation, is titled *The Science Investigation Workshop*. It was designed and developed by Richard Gott, Shawn Roberts and Sandra Duggan at the University of Durham, and consists of "The Eggs of Albatros" and the "Squash Balls" databases. For the purpose of this study, we will concentrate on the "Squash Balls" database, as did our intervention. Figures 1 and 2 present the user interface of the simulation environment.



Choose a ball and place it in the water bath.

If you want, you can change the temperature of the water.

Figure 1. The interactive database simulation "The Squash Balls" provides users with an environment in which to explore the potential influence of many variables on the bouncing of squash balls.



Now drop the ball from the top of the metre ruler:

Figure 2. The rebound height of the ball, as measured by eye (the data is retrieved from the database of the simulation).

The simulation package enables users to investigate four variables that might possibly affect the rebound height of a squash ball. In each trial the rebound height is automatically measured (recalled from the database file), and is presented on the screen as if it had been measured by eye or other techniques, such as video recording.

The children had time to familiarize themselves with the simulation environment. Several questions for investigation had been discussed and children were asked to design and implement valid experiments using the simulation, record the "measurements" obtained and use them to formulate a conclusion as to whether the variable of interest really did appear to affect or not the rebound height of the ball.

Throughout the intervention children worked in groups of three and kept laboratory notebooks. Their work was mostly guided by the curriculum materials. The instructor was constrained to leading semi-socratic dialogues at specific points in the curriculum. These conversations relied on instructor led questions that were aimed at eliciting detailed group difficulties and guiding the children to address them. The conversations also provided feedback (through questioning and reflection) and gave guidance as to the next steps in the group's work. The actual conversations and the detailed procedure followed varied widely from group to group as the children came up with different issues they wanted to explore. However the curriculum provided the necessary guidance to keep them on target even if the path varied and tangents were seldom avoided.

Evaluation

A week after the computer-based intervention, a post-test *(Post-test 3)* was administered that was designed to assess the participants' ability to apply the control of variables strategy in designing experiments. Post-test 3 was of the same format as Post-test 2 and was based on the context of balls and ramps. One month after completion of the intervention, Post-test 2 (now renamed *Post-test 4*) was again administered to the same participants for two purposes:

g) to make a measurement on the degree of retention of the control of variables strategy, and
h) to obtain comparable pretest (*Post-test 2*) and post-test (*Post-test 4*) results on the intervention that

utilized the interactive database simulation package.

RESULTS

Children's responses to both Post-test 3 and Post-test 4 were analyzed using pnenomenographic analysis.

The results demonstrate significant gains in children's ability to

- identify investigable questions,
- identify the variables involved,
- decide which variable has to be changed, those that have to be kept constant, and the one that has to be measured (mental application of the control of variables strategy),
- isolate the measurements from a given table that differ only in the independent and possibly the dependent variable, while all others are controlled
- make comparisons between the values of the measured variable, and
- formulate a conclusion as to whether the independent variable influences or not the dependent variable.

The categories of reasoning that emerged from the phenomenographic analysis were then classified into three categories based on whether the overall response was deemed as correct or not and whether it was appropriately explained. The participant success rates in each of the four tests are presented in Table II. We decided to present the results of Post-tests 3 and 4, as well as the results of the tests prior to simulation use, in order to make the comparison more obvious.

Table 2. Participant success rates in Post-tests 1, 2, 3 and 4

		Correct response with correct reasoning	Correct response with inadequate reasoning	Incorrect response
Prior to simulation use	Post-test 1	73 %	24 %	3 %
	Post-test 2*	0 %	13 %	87 %
After simulation use	Post-test 3	73 %	6 %	21 %
	Post-test 4*	79 %	0 %	21 %

* *Post-tests 2 and 4 were identical.*

Typical answers in each of the three categories of responses obtained from the analysis of Post-tests 3 and 4 are quoted below. Prior to each set of quotes we re-iterate the main task question.

Post-test 3

Does the distribution of mass influence the time a ball takes to roll down a ramp?

Correct response with correct reasoning:

"The question is: Does the distribution of mass affect the time of flight of a ball running down a ramp? In order to respond to this question, I have to select measurements 3 and 4, because only in those two measurements the distribution of mass changes, while all the other variables are kept constant. Observing the time of flight, I conclude that the distribution of mass affects the time of flight"

Correct response with inadequate reasoning:

"I will select measurements 3 and 4, because the balls in these measurements are made of the same material and they differ in mass distribution (hollowness)"

Wrong response:

"I will select measurements 2 and 3 because in these measurements the hollow ball ran faster than the other one"

Post-test 4

Does the color of the ice cream wrapper affect the melting time?

Correct response with correct reasoning:

"The color of the ice cream cover does not affect the time it needs to melt. I selected measurements 1 and 2 and I said: since the ice cream flavor and the mass are the same in both measurements, and they differ only on the color of cover, if the cover's color affected the melting time, the time would be different in these measurements. As I observed in the table, the time is constant in both measurements, so the cover's color does not affect the melting time".

Wrong response:

"The color of the ice cream cover does not affect the time needed to melt, since both ice creams are in the same place. If we placed one in a shadow place and the other under the sun, the time of melting would be different".

DISCUSSION

Our results demonstrate convincingly that it is possible for children aged 11-12 to acquire the control of variables strategy and to apply it in designing experiments and drawing conclusions from experiments in varied contexts. There are three aspects of our curriculum development effort that we believe have made this possible:

- The rigorous research base that underpins and guides all our curriculum development effort, enables us to make refinements in an iterative cycle of design, implement and evaluate. These refinements gradually yield the robust curriculum that can be implemented away from its site of development with comparable large gains in real understanding.
- The integration of thinking skills, epistemological awareness and conceptual understanding as well as the emphasis on inquiry-based collaborative learning make the curriculum challenging and, at the same time, keep children engaged for the extended periods of time necessary to develop some of the fundamental thinking skills.
- The flexibility in adopting technological tools where they are available and useful in order to fulfil learning objectives and to guide students to overcome specific difficulties identified through research.

ACKNOWLEDGEMENTS

We would like to express our thanks to Professor Richard Gott from the University of Durham for making the Science Investigation Workshop available to us. We would also like to acknowledge the support of the European Commission for funding part of this work through the program INCO-DC-973324.

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