An ICT simulation program to be used as a support and/or evaluation tool for scientific thinking in primary education

Kristof Van de Keere, Nele Mestdagh, Peter Dejonckheere, Stephanie Vervaet & Isabel Tallir

Teacher Education, University College VIVES, Belgium

Abstract

Scientific activities offer rich opportunities for inquiry learning. The latter is done by stimulating skills such as the examination of variables in small scientific research projects and the systematic and methodical execution of such projects. This research examines the effectiveness of teaching these research skills to 11/12-year-old pupils by means of an ICT simulation program which examines pupils’ understanding of scientific concepts. In the first stage of the research, the pupils received lessons on how to examine variables. In the next stage, the pupils set about using the ICT simulation program. After having used this program, the pupils filled in a test using pen and paper about the examination of variables in research activities (=variable test). The aim was to investigate if there was a connection between the results of the variable test and the smoothness (=in number of steps and speed) with which the pupils had solved the scientific research questions in the ICT simulation program. The results show that pupils who obtained a good score on the variable test were also swift problem solvers while working with the ICT simulation program. In other words; they required less time to select the correct variables in the ICT simulation program. On the basis of these results, it can be concluded that the ICT simulation program can be utilized as a useful evaluation tool, as a support tool or as a tool to go deeper into the learning of research skills such as the examination of variables and the systematic and methodical solving of research questions within science education.

Introduction

In 2005, the Flemish Government conducted a poll with the aim to map pupils’ performance against students’ attainment levels in the domain of science. This poll consisted of an observation assignment and two investigations and was conducted with pupils of the sixth grade (11 to 12 years old) (Vlaamse overheid, 2005). The results of this poll illustrated the fact that the pupils, on the one hand, had acquired the basic research skills (including observation skills) required at the national specified attainment levels of science classes. However, on the other hand, it became clear that pupils did not sufficiently master the skills of systematically and methodically performing investigations.
The polls showed that pupils encounter difficulties when planning an investigation in response to a research question, and which provides an answer to this question.

**Theoretical exploration**

There are different ways of teaching primary science. For instance, one way is through activities which focus on the paradigm of ‘conceptual change’. This kind of activity stimulates the formation of concepts which change existing students’ concepts in various science domains. In order to stimulate conceptual change, activities need to be set up which provoke direct conflict between students’ experience of how the world works and their existing beliefs of how it should work (Kang et al., 2004). Other approaches can involve, for example, activities which focus more on the processes of logical reasoning and finding scientific evidence. For instance, teaching can be directed towards the enhancement of higher-order thinking skills such as hypothesis construction, designing scientific investigations, formulating good scientific questions, or interpreting data (Chin & Kayalvizhi, 2005).

However, these kinds of activities are not common in science education. In science education the focus tends more to be on obtaining knowledge and understanding of scientific concepts (e.g. knowing why a boat floats while a small needle sinks) and facts (e.g. knowing that water boils at 100 degrees Celsius). Klahr, Zimmerman and Jirout (2011) argue that science education should be based on a dynamic interaction of domain-general strategies (such as controlling variables) and domain-specific strategies (such as developing conceptual knowledge).

For example, domain general strategies refer to problem-solving strategies that are involved in the discovery and modification of theories about causal relationships (Zimmerman, 2000). Such strategies are needed in order to plan experiments or to investigate hypotheses through experiments in search to answer (Dejonckheere et al., 2010). On the other hand, one can take a domain-specific approach to learning science focused on learning scientific concepts and how these change in pupils’ minds while experimenting or during instruction (Zimmerman, 2000). For both types of knowledge, three types of scientific processes can be distinguished through science investigations which consist of: 1) forming hypotheses, 2) designing and running experiments and 3) evaluating the evidence (Klahr et al., 2011).

Let us consider one particular example, for instance, when focusing on the concept, forming hypotheses, experimenting and evaluating results related to what will happen if two objects of different weights are released from the same height, many children will think that the heaviest object will reach the ground first. When this is tested with a feather and a stone released from the same height, this theory is shown to be correct from a practical point of view. But when the children are asked to do the experiment again with two stones of different weights, their ideas about the concept will no longer hold because both stones reaches the ground at the same time (Eshbach & Fried, 2005). Such experiments focus mainly on the understanding of scientific concepts; in this case the action of air resistance and acceleration due to gravity. But the activity can also be viewed only from a process perspective, focusing on hypothesis forming, experimenting and evaluation referring to logical reasoning and the understanding of setting up non-confounded experiments without concern for the underlying domain-specific knowledge (Klahr et al., 2011). For example, children can learn about how to answer a scientific question by setting up two experiments that differ only on one variable (e.g. weight). This is called a controlled comparison strategy (e.g. Chen & Klahr, 1999; Klahr, 2000).

Thus, being able to identify the right variables involved in a research question is a very important strategy in the process towards finding the systematic and methodical solution to any research question (Dejonckheere et al., 2011). Let us illustrate this with the following example: ‘are floating and sinking the same in salt water and in tap water?’. The independent variable in this research question is the use of salt water or tap water - salt (NaCl) or no salt in the water; the dependent variable is floating or sinking (figure 1).
If pupils can correctly name the variables in a research question, and examine them during the research process, there is also a greater chance that they will successfully complete the investigation.

Although it is essential in educational settings that children obtain scientific knowledge, it is also important to focus on scientific reasoning skills and how children’s thinking processes can be developed over time. They consequently gain self-regulation, which is an active and constructive process in which learners control their cognition, behaviour, and motivation with regard to specific tasks (Schunk, 2005).

Through planning, pupils decide on the order in which various tasks are to be carried out and the time required to solve a specific problem. In addition, monitoring skills allow pupils to pay attention to the learning process itself and observe how they can control this process developing over time. A number of studies have shown the effectiveness of teaching self-regulation in order to improve learning in general and scientific thinking in particular. For instance, the Inquiry Cycle, a heuristic concept consisting of 5 steps (question, predict, experiment, copy, apply) (White & Frederiksen, 1998) has been shown to improve scientific thinking of children between 12 and 15 years old. The program developed by White and Frederiksen aimed to provide pupils with insight into physical phenomena such as force and motion, but also into how scientific knowledge is developed. The authors argue that the fact that students have difficulties with the scientific disciplines is not related to the course content, but more to them not knowing how to generate knowledge and consider the learning process involved. The teacher can encourage self-regulation in scientific thinking by guiding students explicitly through the different steps of the scientific thinking process, by posing the right questions (e.g. what is the problem that needs to be tackled? What do you think the answer is? Can you define which variables will affect the outcome? etc.). In this way, the teacher serves as an facilitator of how to think in a reflective and structured manner. From this point of view, teachers should: (a) focus the attention of learners on the scientific process rather than on the scientific content of the problem; (b) focus the attention of learners on the task goals; and (c) encourage learners to reflect on the operation processes than the outcome content.

In the present study, self-regulation was taught through an instructional model called the scientific thinking circle (or Inquiry Cycle), which was presented explicitly to the children. The Inquiry cycle acts as a heuristic concept, dividing up the (scientific) problem into manageable pieces in the form of a cyclic step-by-step plan.

ICT can be a means of coaching students through the inquiry cycle. The students go through the diagnostic problem-solving process by choosing from action menus, including identifying the right variables in the research question. In this way, an ICT simulation program can support pupils in their thinking and learning processes (de Jong & van Jolingen, 2009). An important aspect of ICT tools is that they can also be used for measures and evaluation. On the one hand, the ICT tool helps the student in the planning process; on the other hand, it helps the teacher to assess the student’s intentions and her/his actual state of knowledge.
The research

In the present study, we investigated the extent to which children’s problem solving behaviour could be measured by using an ICT simulation program in which scientific problems were presented as simple tasks in the form of problems to solve through a research question set. Children needed to solve this research question by going through the inquiry cycle; the only way they could solve the question was by controlling variables throughout the research process.

Research design

Methodology

During the investigation, an ICT simulation program was used to verify if 11-12-year-old pupils (n=73, 26 boys, 47 girls) were able to solve a scientific research question systematically and methodically. In the first stage, the pupils were offered relevant classes involving investigative activities in which the examination of variables within a research question (the variables theory) was explained. The classes were given by a senior college student (bachelor in primary education) of a West-Flemish (Belgium) college. During these lessons, different research questions were tackled, but the focus was on the way of solving these questions, on the same methodology. The research question was introduced to the children through a story, a demonstration or a short movie in order to illustrate the problem and in order to make it relevant to their world (e.g. riding down a slope with a bicycle is fun, but how can I go down a slope as fast as I can?). The children could then expand their ideas in the class and try to find an answer through free exploration in small groups. During this free exploration, teacher guidance was minimal. The children seldom conducted fair experiments with controlled variables out of their own initiative. Therefore, during a next phase in the lesson the teacher intervened in this exploration by providing structure to the inquiry process. During this phase, the goal is to explicitly determine the variables that can be examined in the experiment (e.g. steepness of the slope; weight of the bicycle; surface used). Next, the children were then divided into groups and each group examined the effect of one variable in the experiment by going through the inquiry cycle (i.e. one group examined the steepness of the slope, another group the weight of the bicycle) ‘step by step’. A worksheet providing guidance for the children was used in this phase. This worksheet indicated the different steps of the inquiry cycle with a picture with a short written piece of instruction for each step. During Step 1, children were encouraged to express or reformulate the problem in their own words. During Step 2, children were encouraged to think of (different) solutions to the problem. The children were requested to consider the next steps of the investigation in relation to the original question. They needed to select a problem-solving strategy and design an experiment to find out what would be the effect of the chosen variable. During Step 3, children were required to perform the operations they had planned as accurately as possible. During Step 4, children were encouraged to pay attention to the relationship between the outcome of the operation and the problem-formulation established during the first step. Every step of the process was visually supported with an image as heuristic support for the children. During the last phase of the lesson, the various groups showed and explained their results, and a conclusion was formulated about the effect of the variables in the experiments.

On completing these lessons, all pupils subsequently were given a short digital examination through the ICT simulation program. Teacher instruction was minimal during this examination and limited only to guiding the students on how to use the ICT simulation program.
The ICT simulation program

The ICT simulation program used in this research can be downloaded at www.wetenschappelijkdenken.be. With the aid of this program, the pupils conducted research into two different scientific concepts: ‘floating and sinking’ and ‘friction’.

The successive phases of the inquiry cycle (figure 2) are illustrated below by means of the research question: How does the ground surface affect the force required to move a cupboard?

During the orientation phase (what to do?), children are confronted with the research question and they must attempt to deduct the right variables from this question (ICT simulation program: screen 2). In the example given, the ‘type of ground surface’ ('soort ondergrond') is the independent variable, while the ‘tractive force’ ('trekkracht') is the dependent variable. There is instantaneous feedback when a wrong option is selected, and only when the right answer is given can the user move on to the next screen.

In the exploratory phase (how to do it?), the children need to select the right discrete independent variables that can influence the dependent variable (ICT simulation program: screen 3). The ‘type of ground surface’ ('soort ondergrond') is the independent variable. Therefore, the two conditions to be tested for their effects on the

Figure 2: The ICT simulation program
tractive force are ‘smooth ground surface’ and ‘rough ground surface’. The selection of the correct variables is a crucial step in the pupils’ inquiry process. Once these have been established, it will be significantly easier to formulate an inquiry plan, because pupils know what to examine.

In the execution phase (execute!), the research is effectively carried out. The ICT simulation program illustrates the effect of a rough and slippery ground surface on the tractive force required to move a cupboard. The pupils can see the outcomes and interpret the data.

In the restructuring phase (evaluate!) the results need to be interpreted. In order to do this, the pupils are given a number of questions relating to the scientific concept in question.

During the execution of the ICT simulation activities, the time each pupil took to complete the ICT simulation program was registered screen by screen. This served as a measurement for the ease with which the pupils solved the scientific research question.

**The variable test**

After completing the ICT simulation program, the pupils were administered a pen and paper test on ‘the examination of variables’ (=the variable test). This test consisted of 9 exercises, similar to the example given below (figure 3). For every correct answer, one point was allocated. For a wrong answer, no points were given. If there was no answer selected, or if the pupils selected two answers, there were also no points given. The score range of this test was ranged between minimum = 0 to maximum = 9.

---

**Figure 3:** Example of an exercise in the variable test

---

Can you find out the effect of light on the growth of small plants by means of two small experiments? (Circle the correct answer)

<table>
<thead>
<tr>
<th>A lot of light</th>
<th>Little light</th>
</tr>
</thead>
<tbody>
<tr>
<td>A lot of water</td>
<td>Little food</td>
</tr>
<tr>
<td>Much food</td>
<td>Little water</td>
</tr>
</tbody>
</table>

**Right experiment**

**Wrong experiment**
Results

The results illustrate a significantly negative correlation between the test scores and the time required by the students to select the correct variables (time screen 2) \((F(1,52)=17.84, p <.001, \eta^2 = .27)\). This means that the students who obtained a high score on the variable test required less time to find the right variables in the ICT task, which implies that they are swift problem solvers (figure 4).

The results also illustrated that the correlation between the required time to select the right variables (time screen 2) and the score on the variable test is not significantly different between boys and girls (figure 5).

Figure 4: Quick problem solvers with the ICT tool tended to obtain a better score on the examination of variables test. This correlation is significant.

Figure 5: The correlation between the required time to select the right variables (time screen 2) and the score on the variable test is not significantly different between boys and girls.
Conclusion

During the phase of inquiry learning using the ICT simulation program, the pupils changed the values of variables and observed the outcome. The inquiry learning process consisted of a number of specific steps, known as the inquiry cycle. Such a cycle forms the basis of scientific thinking and is the process followed during scientific research. Adhering to the steps in this cycle also stimulates pupils to develop new knowledge and research skills (such as the examination of variables). While conducting experiments this way, it is of the utmost importance that pupils learn to regulate their own learning process. Self-regulative processes encompass planning and monitoring (Dejonckheere et al., 2009). These processes are of the utmost importance in a learning environment where pupils are to conduct experiments independently (de Jong & van Jolingen, 2009). The supervision of these self-regulative processes can be carried out by a teacher in collaboration with fellow pupils, but an ICT simulation program can also provide built-in support (White & Frederiksen, 1998; de Jong & van Jolingen, 2009) when there are no additional human resources. Such computerised simulations have proven to be very effective and provide significant enhancement of the learning process (Klahr et al., 2011; Quintana et al., 2004). This research illustrates that ICT simulation programs can also be used as an evaluation tool after a series of lessons on inquiry learning. Such an ICT simulation program is not only interesting because it can have an effect on the motivation of the children, but also because it can measure some parameters automatically such as getting to the right answer, and even more importantly, obtaining insight into the process of inquiry by measuring the time pupils need for each step of the inquiry process. The amount of trials children take during the inquiry process can also be measured, but this was not tackled in this article. We found that children who obtained a high score on the pen and paper test required less time to find the right variables in the ICT simulation program, meaning they are swift problem solvers. Thus, the ICT simulation program can be used as an evaluation tool which automatically generates important information for the teacher on the inquiry processes individual pupils go through. Furthermore, it has the potential to be implemented successfully as a form of assessment of the learning process related to solving scientific research questions in which the examination of variables plays a central role.

References


