A VIRTUAL JOURNEY WITHIN THE ROCK-CYCLE: A SOFTWARE KIT FOR THE DEVELOPMENT OF SYSTEMS-THINKING IN THE CONTEXT OF THE EARTH'S CRUST

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ABSTRACT

Developments in the last few years in earth science education can be characterized by a shift towards a systems approach to teaching and curriculum development. The software "A Virtual Journey within the Rock Cycle", a microworld game, was developed in order to assist junior and senior high school students, who have already learned about the rock-cycle's processes and products, in developing a dynamic and cyclic understanding of the earth's crust system. Preliminary observations indicated that that the software induced great enthusiasm, fostered collaborative group work and brought students to recall and reflect upon knowledge previously learned. Additionally, it was found that the teacher's role as a mediator was critical for enabling students to maximally benefit from the software.

Keywords: Education – computer assisted; education – precollege

INTRODUCTION

Developments in the last few years of earth science education can be characterized by a shift towards a systems approach to teaching and curriculum development. This shift can be illustrated by the main theme of a conference, held in Hawaii, "Learning about the Earth as a system" (Fortner, and Mayer, 1998). This theme was chosen "because it emphasizes the importance of reexamining the teaching and learning of traditional earth science in the context of the many environmental and social issues facing the planet… it is imperative that students at all grade levels and from all cultures have an understanding of how the Earth works" (Fortner, and Mayer, 1998, p.3). Orion (1998) claims that systems-thinking in the context of earth sciences, is a fundamental step in order for students to reach environmental literacy. He claims that understanding the reciprocal relationships within, and between each of the Earth systems i.e., the geosphere, the hydrosphere, the atmosphere and the biosphere (including mankind), will enable students to become thoughtful decision-makers, concerning environmental issues in the future.

Systems thinking, i.e. the type of thinking needed for understanding systems, have been extensively studied in many domains, including the social sciences, (e.g., Senge, 1998), medicine (e.g., Faughnan and Elson, 1998) psychology (e.g., Emery, 1992), decision making (e.g., Graczyk, 1993), project managing (e.g., Lewis, 1998) and engineering (e.g., Fordyce, 1988). According to O'connor, and McDermott (1997), a system is an entity that maintains its existence and functions as a whole through the interaction of its parts. Systems-thinking according to them, "looks at the whole, and the parts and the connections between the parts…" Frank (1999) regards such thinking, as a higher order thinking skill, and claims that it is an important way of thinking in many scientific and non-scientific domains. The significance of systemic thinking was emphasized by Senge (1998), who claimed that in a world of information explosion, in which systems are becoming more and more complex, systems-thinking is a fundamental skill.

In a study characterizing the specific systems-thinking required for understanding the rock-cycle (Kali et al., 2000), three elements of general systems-thinking were defined as: a) understanding of the parts of a system, b) understanding the connections between these parts, and c) understanding the system as a whole. Accordingly, it was suggested that in the rock-cycle, the first element (i.e., the parts) involves acquaintance with different materials comprising the crust of the Earth. These materials include different types of rocks, unlithified sediments and magma, as well as the geological processes that produce them. The second element (i.e., relationships) involves understanding causal relationships between specific processes and their input and output products. The third element (i.e., the holistic aspect) involves understanding that each output product from one process can serve as an input product to another process, so that most material of the crust is recycled through endless chains of processes and products.

In the same study (Kali et al., 2000), it was found that an understanding of the dynamic and cyclic nature of the rock-cycle was not reached by most students at junior high school level, even when they understood all the relevant geological processes and their products. However, a summative knowledge integration activity brought about a meaningful improvement in students' views of the rock-cycle. Following this activity, students became more aware of the dynamic and cyclic nature of the rock-cycle. Moreover, their ability to apply this awareness and construct sequences of processes, representing material significantly improved (Kali et al., 2000).

As a result of this study it was decided to develop additional aids for assisting students to integrate their knowledge of the rock-cycle. We searched for a type of activity that would make the dynamic and cyclic nature of the Earth's crust more concrete. One such activity could be for students to follow a journey, such as the one described by Jules Verne in his "Journey to The Center of the Earth", and "participate" in activities such as riding a lava flow. This would certainly "bring alive" the idea of material transformation within the rock-cycle. Although such an educational field trip is, regretfully, beyond the scope of our capabilities, a virtual journey was chosen as a satisfactory alternative and the computer was chosen as the tool for the activity.

The computer is a tool well-suited for enabling students to experience such a journey. An important advantage of the computer is that it enables the construction of microworlds (Elshout and Veenman, 1992), which have specific sets of "rules" that students can interact with (for instance a rule of the rock-cycle is that slow cooling of magma will always create plutonic

Rocks	Geological Processes	Environment of Formation
Magmatic Rocks		
Granite	Slow crystallization of magma	Pultonic zone: pockets of magma in the Earth's crust
Basalt	Rapid crystallization of magma	Volcanoes: continental and mid-oceanic
Metamorphic Rocks		
Gneiss	Burial and metamorphism of any rock*	High temperatures and pressure at the depth of the Earth's crust*
Schist		
Sedimentary Rocks *A) Biogenic Rocks*		
Limestone	Extraction of calcium carbonate from seawater by organisms, which build coral reefs and shells, deposition and lithification	Shallow Sea
Chalk	Extraction of calcium carbonate from seawater by forminifera, deposition of their shells, and lithification	Open Sea
Chert	Extraction of silica from seawater by radiolaria, deposition of their shells and lithification	Open Sea
Phosporite	Accumulation of reich organic material deposits containing fish skeletons and teeth	Fertile areas of the sea (upwellings)
B) Clastic Rocks		
Sandstone	Erosion of exposed rocks, transportation and deposition of sand grains by currents (streams or wind**)	Rivers, Dunes**
Marl	Erosion of sedimentary rocks, transportation and slow deposition of fine sediments	Lakes and deltas
Clay	Erosion of magmatic and metamorphic rocks, transportation and deposition of fine sediments	Lakes, Deep Ocean
C) Evaporitic Rocks		
Dolomite***	Evaporation and successive increasae of salt concentration to the degrees appropriate for dolomite, gypsum, and halite to crystallize	Lagoon with limited seawater inflow and high rates of evaporation
Gypusm		
Salt		

Table 1. Rocks, geological processes, and environments of formation included in the software (simplified to suit high-school level). * Distinction between the formation processes of schist and gneiss is not included in the software. **Distinction between the rocks that form these environments is not included in the software. * Dolomitization processes are not included in the software.**

rocks). The capability of the computer to store and run high quality animation enables such microworlds to provide students with vivid simulated experiences, which in many cases (such as with many of the rock-cycle processes) could not be experienced by other means. An additional decision was to design the activity as a game. Evidence exists indicating the effectiveness of playing on students' curiosity, divergent thinking and motivation toward learning diverse scientific topics (e.g., Shaw, 1983) and even on attitudes toward the environment (Henniger, 1987).

Following these considerations, the software "A Virtual Journey within the Rock Cycle" was developed. (English and Hebrew versions can be downloaded at http://yaelkali.org). This microworld game is aimed in assisting junior and senior high school students, who have already learned about the rock-cycle's processes and products, in developing a dynamic and cyclic understanding of the Earth's crust system.

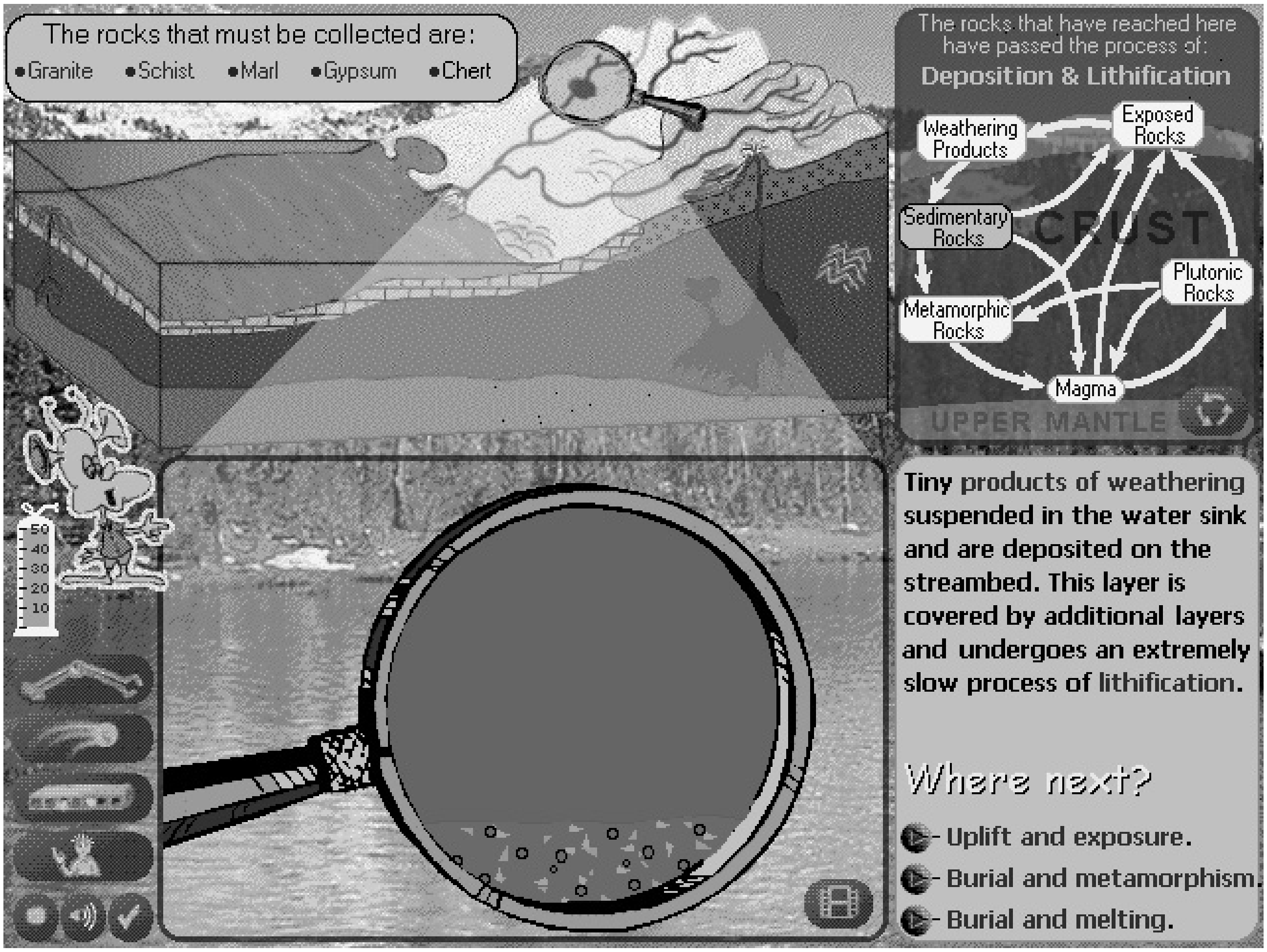

Figure 1. The interface of the software including the four windows.

DESCRIPTION OF THE SOFTWARE

Contents - The software includes animation, photos, figures and verbal explanations of the geological processes, the environments of formation and the rocks presented in table 1. (The rocks were chosen to meet the Israeli earth-science curriculum, for which the software was developed). Two versions are included in the kit, designed for different levels of knowledge. The senior high school version deals with concepts related to all the rocks included in table 1. A version adapted to junior high school level omits the evaportitic rocks, to avoid dealing with chemical concepts such as dissolution and crystallization from a saturated solution.

Background Story - When students open the software for the first time, they are introduced with a background story, presenting Cosmo and Stella, a couple of friendly aliens who had to land on the Earth from the outer space. Cosmo and Stella are looking for replacement parts, made of rocks, in order to repair their spaceship. To assist them in this mission, the student gives the aliens advice for navigating within the Earth's crust, by choosing geological processes, which bring Cosmo and Stella to different rock forming environments.

Rules of the Game - In order to complete the mission, the student must assist Cosmo and Stella to collect five rocks (or four in the junior high school version), and throw away any extra rock, making the least number of moves within the rock-cycle, with a restricted amount of Methane for the aliens' breathing. In order to collect a rock, the student must assist Cosmo and Stella in moving from one environment of formation to another, by choosing appropriate geological processes. This continues until the aliens reach the environment in which the student believes the specific rock is formed. When a rock is requested in the correct environment the student receives a positive feedback – the aliens use their geological hammer to break a fresh piece of the desired rock and install it in the spaceship. In cases when a specific rock is requested in the wrong environment, the rock that is formed in that environment is collected, but if this rock is not included in the mission, the student will have to assist Cosmo and Stella to throw it away. However, the rock cannot be thrown away immediately, and the student will have to complete a whole cycle of geological processes in order to come back to the specific environment and get rid of the unnecessary rock. If by chance this rock is included in the mission, it is collected, but the student receives a "yellow card" for trying to pick

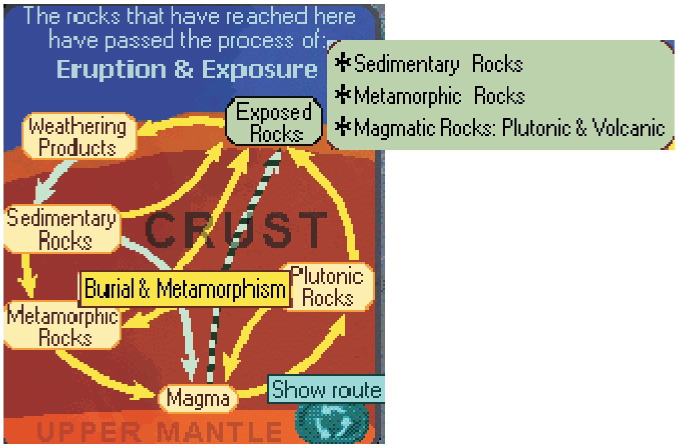

Figure 2. The rock-cycle model window.

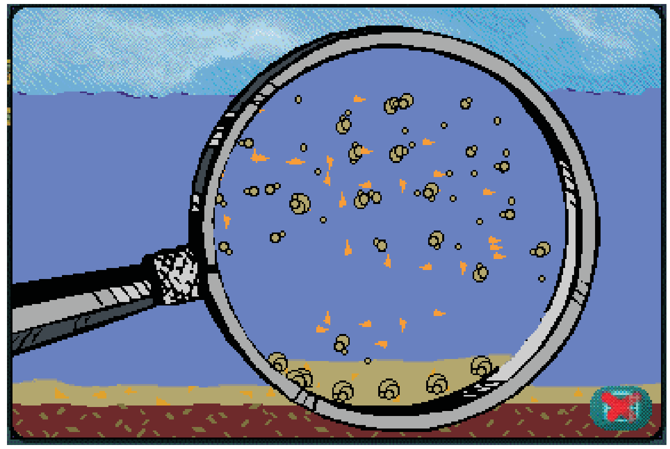

Figure 3. Animation in the zoom-in window: Example from open sea environment

a rock in a wrong environment. The game continues in this manner until either the mission is completed and the aliens fix the spaceship, or is stopped by one of the following conditions: a) more than two yellow cards are received, b) the aliens' Methane tank of 50 breaths is finished due to too many actions.

Interface - The interface of the software includes the following four windows that appear on the screen throughout the whole game (Figure 1):

1) The rock-cycle model window (Figure 2): This window provides the student with a graphic diagram that includes all the geological processes (represented as arrows) and their products (represented as rounded rectangles), which together represent the cyclic system of the Earth's crust, known as the rock-cycle model. The student's route throughout the rock-cycle is constantly updated, and represented by colored arrows in the model. Pointing at each of the arrows in the diagram pops-up a tag indicating the geological process it represents, and pointing at the rectangles, pops-up tags with additional information of specific products. A "show route" button highlights the arrows according to the order in which the student entered them. This button also counts the number of moves made by the student within the rock-cycle model.

2) The environments of formation block-diagram window (Figure 1): In this window all the environments of formation are illustrated in a block-diagram model. Such representation emphasizes the spatial relationships between the different environments. A magnifying glass indicates the location of the environment where Cosmo and Stella are found at any moment of the game.

3) The zoom-in window (Figures 3 and 4): This window illustrates the specific environment that is indicated by the magnifying glass of the block-diagram window. Each environment includes animation illustrating the geological processes occurring in the environment, and their products. For example, in the open sea environment, animation illustrate the sedimentation of foraminifera shells on the sea floor. Animation also illustrate geological processes, which transform materials between different environments of formation. For example, when the student chooses the process of burial and metamorphism, animation illustrate the alignment process of the minerals as the pressure and temperature rises. (Figure 4a and 4b).

4) The description window (Figure 5): In this window, the processes occurring in the zoom-in window are described. At the end of each description, options are presented for navigation within the rock-cycle. The question "Where next?" is presented, with several navigation buttons representing geological processes that can act on the products of the specific environment. Clicking on any of these processes, models material transformation from the specific environment, to a new one, caused by the geological process chosen by the student. This transformation is represented by the interface as follows:

A) A new arrow is added to the route represented in the rock-cycle model window.
B) The magnifying glass of the environments of formation block-diagram window moves to point on the new environment.
C) A new environment is illustrated by animation in the zoom-in window
D) A new description of the environment appears in the description window, with new options for further navigation.

Many terms, which are usually novel to students before learning about the rock-cycle, are used in these explanations. Since the software is designed as a knowledge integration concluding activity, and not as means for primary learning about geological processes, such terms are not extensively discussed. However, in order to encourage students to concentrate on the dynamic and cyclic aspects of the rock-cycle, rather than on newly learned terms, pop-up tags are used as reminders of the meaning of such terms.

PEDAGOGICAL CONSIDERATIONS IN THE DESIGN PROCESS

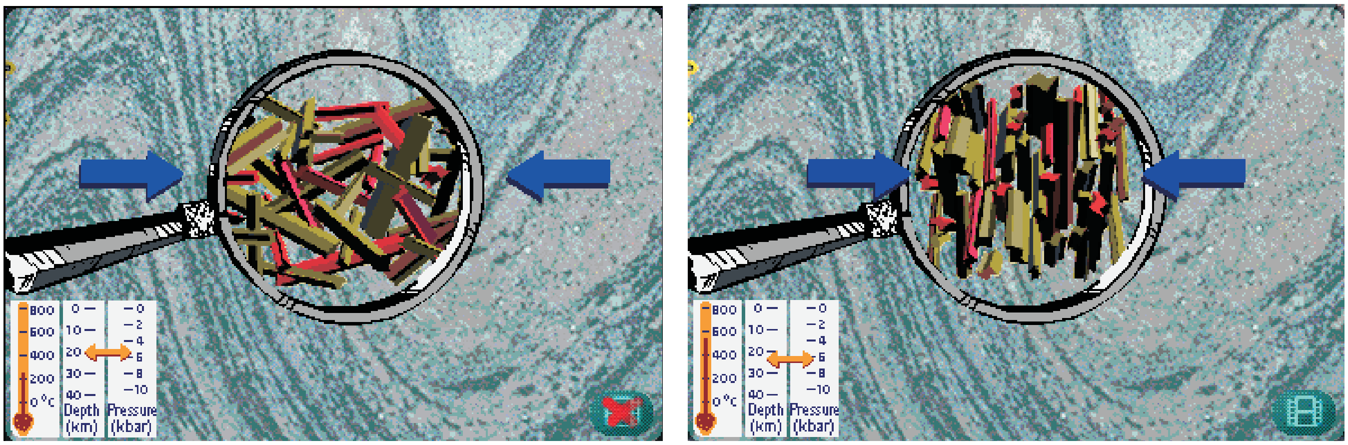

Figure 4. Animation in the zoom-in window: Example from metamorphic environment. Left , beginning of animation. Right, end of animation.

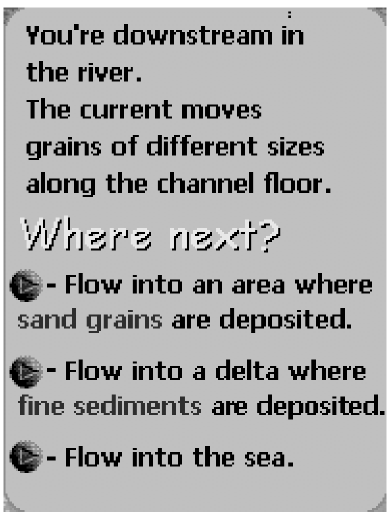

Figure 5. Navigation buttons and pop-up reminders in the description window.

The restrictions in the rules of the game, designed to add an element of excitement, are actually a result of pedagogical considerations based on the study about systems-thinking in the context of the rock-cycle (Kali et al., in press). For instance, restricting the number of moves in the rock-cycle, and the number of the Aliens' breaths, is aimed in motivating students to carefully plan Cosmo's and Stella's route within the rock-cycle, rather than proceed in a trial and error route. It is suggested that such planning of cyclic routes of geological processes might assist students in developing systems-thinking in the context of the rock-cycle.

Another example is the restriction on the number of yellow cards permitted in the game. This rule, which also has a motivational effect, is aimed at preventing students from guessing, and encouraging them to recall the pieces of knowledge previously gained about the rock-cycle, and integrate these pieces into a holistic view of the system.

An additional decision was the number and the types of rocks to be collected in a single mission. The decision to require five types of rocks (one of each rock-category) was aimed to encourage the student to pass several cycles within the system (at least three cycles are needed in order to compete any mission). In this manner students can construct long sequences of processes and products, a process that might assist them in developing the systems perception of the rock-cycle.

The design of the interface in four windows that are mutually present on the screen during the whole game is based on the notion that multiple visual representations are beneficial in illustrating complex ideas (e.g., Linn, 2000). Although all four windows reflect the location of Cosmo and Stella at any moment within the rock-cycle, each window emphasizes different types of information.

The "rock-cycle model window" provides information of the rock-cycle, emphasizing the relationships between different geological processes, and the sequences of processes creating material transformation within the rock-cycle. Apparently, this window provides all the information needed for understanding the dynamic and cyclic nature of the system. However, evidence exists that students who studied the contents of the rock-cycle and were able to draw this model did not necessarily internalize its dynamic and cyclic aspects (Kali et al., in press). The symbolic information of this window is therefore supported by the other three windows.

The "environments of formation block-diagram window" provides the student with lively graphic information illustrating the various environments of formation, and of the spatial relationships between them. The movements of the magnifying glass between these environments might assist students to perceive the material transformation within the Earth's crust more realistically than the symbolic information of the "rock-cycle model window".

The two windows described above present general information about geological processes. The "zoom-in window", and the "description window" enable students to focus on the details of processes occurring in specific environments of formation. For example, the successive processes of evaporitic crystallization, is represented by the general term "sedimentation" in the "rock-cycle model window", or as a general illustration of a lagoon the "environments of formation block-diagram window". Such processes are described in detail and illustrated in the "description window" and the "zoom-in window". It is suggested that the illustration of such processes, and their verbal description, together with the other more general windows, could enable students to relate processes in specific environments to a more general view of material transformation within the rock-cycle.

IMPLEMENTATION AND PRELIMINARY EVALUATION

The software "A Virtual Journey within the Rock Cycle" was implemented in several junior and senior high school classes. Our preliminary observation indicate the following points:

1) The software aroused great enthusiasm among students:
   - Students tended to enter the game many times in order to achieve higher scores, competing with themselves and with other students.
   - Many students chose to remain in class and continue playing at the expense of their free time.
   - Many students asked for a copy of the software, in order to continue playing at home.
   - Students' remarks showed excitement and enthusiasm.

2) The software fostered collaborative group work among students. Although students had the opportunity to work individually, in many cases, they chose to work in groups of two or three students. In such cases many of students' discussions were aimed on better understanding of the contents of the software by mutual discussion with their peers.

3) The interaction with the software encouraged students to recall knowledge previously learned. In order to complete the mission in the least number of moves, many students opened their booklets, and considered their answers to questions related to laboratory experiments illustrating geological processes.

4) A general pattern characterized the progress of many students while working with the software. This pattern included preliminary "trial and error" playing, without paying attention to most of the information provided by the different windows of the interface. Students concentrated on the "Zoom-in" window, and the navigation buttons of the "description window", and tended to ignore the "rock-cycle model window" and the "environments of formation block-diagram window". Therefore, they were not engaged in planning their journeys. It is suggested that this pattern of interaction, which in many cases resulted in losing the game, could not foster systems-thinking among students. However, this stage was in most cases followed by a more sophisticated interaction stage, in which students wisely used the interface of the software for planning their journeys throughout the rock-cycle. Although many students reached this stage independently, motivated by the software's feedback, in other cases, the teacher's intervention was needed to encourage students to do so.

5) The teacher's role as a mediator was substantial. When the teacher's mediation was needed, he/she directed students' attention to the model of the rock-cycle, and to the block-diagram illustrating the spatial relationships between the environments which they had passed though. The teacher encouraged students to plan their journeys, using this information. It is suggested that this mediation was crucial in their ability to exploit the pedagogical and affective potential of the software.

A further study is planned in order to a) reexamine the preliminary findings, b) find optimal manners of implementing the software, and c) assessing its effect on students' systems thinking in the context of the rock-cycle.

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