The Rock-Cycle Program as a Means for Fostering Thinking Skills: Development, Implementation and Research

Dissertation Submitted for the Degree
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General Introduction and Summary and General Conclusions
(instead of Abstract)

General Introduction

1. The context of the study

The Israeli science education at the junior high school level has undergone a major change during the last several years. This change stemmed from a decision to merge the different scientific disciplines, which were formerly studied independently, together with technology, to form a new curriculum named “Science and technology” (The Israeli ministry of education, 1996). In addition, it was decided to incorporate earth sciences as one of seven major themes, in the new syllabus of this subject.

The introduction of the earth sciences into the new syllabus led to a dramatic change in the domain of earth science education. Before this revolution, the only earth science related topics available to Israeli junior high school students, were those included in the geography curriculum – a social science context. However, in that context, earth science topics focused on descriptive phenomenology. With the new syllabus, the earth sciences were referred to, for the first time, as part of the natural sciences in the Israeli junior high school curriculum.

This local change in earth-science education occurred in a period of a worldwide movement towards the environmental earth systems approach of the earth sciences education. Mayer, (2001) claims that it is now an opportunity for the science education to lead science into a new era where it can provide the knowledge to counter the devastating environmental problems that have been a by product of a century of war and economic conflict. In order to do that he claims that educators must fundamentally change science education founded on a view that science is a study of the Earth system. This shift can also be illustrated by the main theme of a conference, held in Hawaii, “Learning about the Earth as a System” (Fortner & 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” (p. 4). The application of this approach in the Israeli new earth science curriculum for the junior high school level is expressed by the learning of earth science contents, within the mega earth cycles approach. A pedagogical decision was taken to arrange these mega cycles in a sequence progressing from the concrete to more abstract. Consequently, it was decided that the program for 7th grade will concentrate on the lithospheric rock-cycle system, the 8th grade program will concentrate on the hydro-cycle system, while the 9th grade program will cover all the earth systems through studying the carbon cycle (The Israeli ministry of education, 1996). The present dissertation deals with the first step in the earth sciences sequence in junior high school -. the contents of the lithosphere, or more specifically, the rock-cycle system.

2. Scientific background

The rock-cycle is a system including the crust of the earth, which is characterized by a cyclic and dynamic nature. The rocks exposed on the surface of the earth are only a small sample in time and space of constant material transformation within the crust, driven by geological processes (e.g. weathering, sedimentation, burial, metamorphism, melting, crystallization of molten rocks, uplift and erosion) (Figure 1). The rock-cycle can be viewed as a closed system, since hardly any material was added or removed from this system in the time involved in students’ observations. Additionally, since the size of the reservoirs of this system was almost constant over this time scale, it can also be viewed as a system maintaining a dynamic equilibrium.

3. Goal and objectives of the dissertation

My main goals In the current dissertation were:

1. To explore the educational potential of a specific geoscience topic, for students' cognitive growth.

2. To find effective practical ways to apply this potential.

More specifically, these goals involved the cognitive development of scientific thinking and systems-thinking among junior high school students within the framework of the rock-cycle content.

In order to achieve these goals, objectives were defined within the three facets of education, i.e., research, curriculum development, and implementation.

A) Research objectives:

1. To characterize students' perceptions of the rock-cycle system at different stages of learning.
2. To examine the effect of knowledge-integration activities on such perceptions.
3. To analyze the above effect in terms of systems-thinking concerning the rock-cycle.
4. To examine the effect of different implementations of "The Rock cycle" program, on students' basic scientific thinking skills, i.e. their understanding of the concepts "observation", "hypotheses", "conclusion".

B) Curriculum development objectives:

5. To develop curriculum materials that would provide students with means for developing systems-thinking in the context of the rock cycle.
6. To develop curriculum materials that would provide students with means for developing general scientific thinking skills.

C) Implementation objectives:

7. To provide teachers with tools for exploiting the potential of the curriculum materials in developing students' systems-thinking and general scientific thinking skills.

Summary and General Conclusions

1. Achieving the objectives of the study

   The general goal of the present dissertation was to provide students with means for development of scientific thinking and systems-thinking, within the framework of the rock-cycle contents. In order to achieve this goal, seven objectives were defined, in the three facets of science education (i.e., research, curriculum development and implementation). The present summary will conclude how each of these objectives was obtained, and integrated with the other objectives to accomplish the general goal of the dissertation.

   Objective 1, 2 and 3 (research facet):

   (To characterize students' perceptions of the rock-cycle system at different stages of learning; to examine the effect of knowledge-integration activities on such perceptions; to analyze the above effect in terms of systems-thinking concerning the rock-cycle).

   The results of the pilot study showed that students gained reasonable understanding of geological processes of the rock-cycle, but lacked the systems understanding, i.e., an understanding of the earth's crust cyclic and dynamic nature. Therefore, knowledge-integration activities, which were aimed in developing systems-thinking in the context of the rock-cycle were incorporated within the curriculum.

   Students' perceptions of the rock cycle were obtained by charcterization of their answers to an open-ended questionnaire, which was administred after a knowledge acquisition stage, of learning "The Rock-cycle" program, and again after the four-hour summative knowledge integration activity. The answers were interpreted using a systems-thinking continuum, ranging from a completely static view of the system, to an understanding of the system's cyclic nature. It was found that after the knowledge acquisition stage, systems-perception of the rock-cycle was not obtained by many of the students. They understood different geological processes and their products, but lacked the dynamic and cyclic conceptions of the system. A meaningful improvement in students' views of the rock-cycle, towards the higher side of the systems-thinking continuum, was found following the four-hour summative knowledge integration activity. Students became more aware of the dynamic and cyclic nature of the rock-cycle. Their ability to apply this awareness, and construct sequences of processes, representing material transformations, significantly improved.

Other examples of a short-term knowledge integration intervention, which followed a knowledge acquisition stage, and also brought considerable improvement in students' understanding, are described in Bagno and Eylon (1997), as well as Hsi and Linn (1997). The success of the summative knowledge integration activity in this study, as well as in the studies mentioned above, stresses the importance of post knowledge acquisition activities, based on knowledge differentiation into the smallest parts of the system, as well as their integration in a systems context.

Objective 4 (research facet):

(To examine the effect of different implementations of "The Rock-cycle" program, on students' basic scientific thinking skills, i.e. their understanding of the concepts "observation", "hypotheses", "conclusion"). It was found that junior high school students have considerable difficulties in understanding basic concepts of scientific inquiry (i.e., "observation", "hypothesis" and "conclusion"). "The Rock-cycle" program provided a powerful environment for fostering such understanding.

Structured inquiry activities, such as those incorporated into "The Rock-cycle" were found as the main scaffold that assisted students in developing their understanding of these concepts. It is suggested that such activities can be used as a primary scaffold in order to enhance skills required for independent open inquiry.

The unique character of geoscience methodology, provided an appropriate framework for the development of scientific thinking skills amongst junior high school students; Inquiry in the geosciences has a unique characteristic, which derives from their involvement with the "experiments" that have already been conducted by nature. Consequently, many geological inquiries are of a retrospective type – trying to unravel what happened in the past, using "fingerprints" left in the earth. Frodeman (1995), describes geology as an interpretive, and historical science, which "embodies distinctive methodology within the sciences". He further argues that "the geologist picks up on the clues of past events and processes in a way analogous to how the physician interprets the signs of illness or the detective builds a circumstantial case against a defendant" (p.963). Edelson, Gordin & Pea (1999) described several aspects of the geosciences as being "observational sciences". We believe that the focus of geology in making inferences from observations, rather than a focus in experimentation (Ault, 1998), is a suitable milieu for internalizing the meaning of some of the most basic constructs of scientific thinking, i.e. observations, conclusions and hypotheses. An additional advantage in geology as a context for learning science, is the possibility to provide students with concrete materials of the earth (e.g., rocks, minerals, soils), from which they can conclude upon exciting phenomena like volcanic eruptions, earthquakes or formation of mountain ranges. The intentional usage of these characteristics in the curriculum served as a fertile framework for students' development of their scientific thinking.

An unexpected gender difference, in which girls outperformed boys in scientific thinking, was found in students' scores before learning the program, and again, afterwards. The unique character of geoscience methodology, together with structured-inquiry and metacognitive activities for reconstructing scientific thinking routes, were found as an appropriate framework for students to develop basic scientific thinking. The co-interpretation of quantitative results with qualitative analysis indicated that the type of teacher (degree of openness to innovative teaching methods, enthusiasm and scientific background) was a crucial factor in students' ability to exploit the potential of "the Rock-cycle". Finally, teachers' management of classroom activities was affected more by teacher characteristics, than by the amount of guidance they received.

Objectives 5 and 6 (curriculum development facet):

(To develop curriculum materials that would provide students with means for developing systems-thinking in the context of the rock-cycle; to develop curriculum materials that would provide students with means for developing general scientific thinking skills).

The design of “The Rock-cycle” activities is derived from the constructivistic and social constructivistic epistemologies (for a detailed description of the program, see article 1 of this dissertation). All the activities in the program are performed in an inquiry method, the main resources of which are concrete items – natural materials of the earth, brought to the lab, or studied in the field. The inquiry is guided by means of a booklet, which includes mainly questions, and only a minimal amount of textual information. In this manner, groups of three or four students work in collaboration to “discover” the geological processes by themselves, following the “bread-crumbs” the designers have left for them on the way. The inquiry is guided in a similar manner to that described by Karplus (1979) in his “learning cycle” strategy. Each chapter in the booklet starts with student observations, which create a certain cognitive conflict. To resolve this conflict, students initially express their own hypotheses and then follow a route of inquiry that was designed for them in the booklet. The role of the teacher is therefore, to mediate between the students and scientific knowledge, by helping students to use the inquiry method to investigate the earth and its processes (Kali, Orion & Eylon, 2000).

To foster students’ awareness of this scientific thinking route, summary activities of Metacognitive Scientific Reconstruction (MSR) are performed at the end of each inquiry activity. In these activities linguistic terms are used as organizing schemes in a metacognitive process. Students examine their investigation with "scientific inquiry spectacles", by characterizing the different stages of the inquiry, using terms like "observation", "hypothesis" and "conclusion".

In order to assist students to develop the systems perception of the earth's crust, knowledge-integration activities, were incorporated within the curriculum in different levels of specificity. The most specific level, in terms of content, were the "Integration questions", which were designed to assist students in relating knowledge they have already gained (processes and products of the rock-cycle) while engaged in inquiring new knowledge. A more general level of knowledge integration activities was the "Construction of the rock-cycle" activity, which consisted of a diagram, in which materials of the earth are represented. After studying each geological process (inquiry activities) students were required to add arrows to the diagram, representing the process that they have just learned. Eventually, when the diagram was completed with all the appropriate arrows, it represents the dynamics of material transformation in the rock-cycle. Finally, a summative knowledge integration activity, which was aimed in assisting students in organizing all the knowledge that they have gained throughout the program, and integrate it in a dynamic and cyclic context, was administered. Two versions of this activity were developed. The first utilized a software program designed for knowledge organization ("KnoW", Svivot Inc.) and the second utilized much simpler technology including a magnetic board and cards. The assignment in both activities was to represent all the material transformation processes and products, which produced a certain rock that was studied earlier in the curriculum.

The findings concerning students' systems-thinking and scientific thinking, indicate that when the activities incorporated within the program were appropriately implemented, these thinking skills were significantly improved. Therefore it is concluded that the curriculum materials provide students with powerful means for developing such thinking skills. However, as noted above, the role of the teacher is crucial for students to exploit the petential of the curriculum materials.

Although a significant shift was found in students' perception of the rock-cycle as a dynamic and cyclic system, the software "A Virtual Journey within the Rock-cycle" was developed to provide students with additional means for further enhancement of this perception. It is suggested that such a perception, together with dealing with authentic and relevant environmental issues, might serve as a first step in students' environmental literacy.

Objective 7 (Implementation facet):

(To provide teachers with tools for exploiting the potential of the curriculum materials in developing students' systems-thinking and general scientific thinking skills)

The intensive investment in teacher training described above was pragmatic, i.e., this investment was aimed to reach the student, which is the "end product" of the educational system. An assumption, which was reinforced by the conclusions of the case-studies, was that curriculum materials would not be able to affect the students without an appropriate implementation of the teacher. The study "A situative approach for assessing the effect of an earth science learning program on students' scientific thinking skills" (article 3) presented three case studies in which the "rock-cycle" program was taught by different types of teachers, who can be characterized as: a) the senior teacher with a firmly fixed teaching approach, b) the beginner, open-minded teacher and c) the enthusiastic teacher lacking sufficient scientific knowledge. In each of these case studies we described very different pedagogies for implementing the program by those teachers, which eventually brought to great variance between the outcomes of the students, in terms of their development of the related cognitive skills.

The outcome of this effort - i.e., the very large number of students who have learned "The Rock-cycle" program so far, and the evidence indicating students' development of scientific and systems-thinking, indicates that the INSET was worth the efforts invested in it.

However, this dissertation suggests that teachers' management of classroom activities is affected more by personality factors, than by the amount of professional guidance they receive. Conventional INSET courses are appropriate for the type of teacher who is open-minded, willing to invest much effort in teaching, and who has an appropriate scientific background. It is, therefore, suggested that heterogeneity of teachers in INSET courses should receive more attention, especially when junior high school teachers, who have diverse backgrounds, are concerned. Pedagogical concerns applied to heterogeneity of students, should be applied also in teacher training. Distinguishing between different types of teachers, and tailoring appropriate programs for each group, might lead to more effective INSET. Such programs may lead to improved cognitive growth amongst students.

2. **Contribution to the Science of education**

   The integrated efforts in the three facets of science education, i.e., research, curriculum development and implementation, which characterized the present dissertation, yielded the following contribution to the science of education:

   Research

   1. Characterization of the educational potential of the geoscience, with an emphasis on (a) the potential of the dynamic and cyclic nature of the rock-cycle for enhancing systems-thinking, and (b) the geoscience unique inquiry method for enhancing general scientific thinking.
   2. Deepening the knowledge about systems-thinking, a cognitive skill that received very little attention in the science education. This study provides evidence that appropriate knowledge integration activities can enhance such thinking.
   3. Presenting new outcomes, some of which are contradictory to those presented in the literature, about scientific thinking, an intensively studied domain. These outcomes contribute to the debate concerning the degree of structure appropriate for the design of scientific inquiry activities.
   4. Developing tools and methods for characterization of students' systems-thinking in the context of the rock-cycle, and for assessment of students' basic scientific thinking skills in a general context (Appendix 4).

Curriculum development

5. Presenting a pragmatic approach for curriculum development integrating between different educational perspectives, using each one according to the “grass root” needs of students and teachers.
6. Developing “The Rock-cycle”, a 34-hour learning program for junior high school students, which exploits the unique potential of the geoscience for fostering students’ cognitive growth, and their first steps in the development of environmental literacy.
7. Developing of four trip modules, to be implemented in “The Rock-cycle” program.
8. Developing the software “A Virtual Journey within the Rock-cycle”, a microworld game, aimed at assisting junior and senior high school students, in systems-thinking in the context of the rock-cycle.

Implementation

9. Large scale introduction of a new discipline, namely geosciences, to the Israeli junior high school educational system.

Suggestions for further research

10. Questions, which the currrent dissertation raised, and require further research are the following:
    - How does the awareness to the holistic aspect of a system effect systems-thinking?
    - Is there a general systems-ability that can be transferred from one context to another?
    - What type of teacher-training could enable different types of teachers to learn and interalize innovative teaching approaches?

- What are all the factors involved in the success of implementation of new learning programs, and what are the proportions between these factors?
- What is the source of the discrepancy between the results of the current study, which indicate higher achievements of girls in scientific thinking skills, and former research concerning gender differences in scientific achievements?