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A Design Based Research of an Earth Systems Based Environmental Curriculum

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This article presents a model for the development of an environmentally oriented unit designed to be implemented as an integral part of the science core curriculum. The program's main goal is encouraging students at the junior high-school level to develop systems-thinking and environmental insight as a basis for environmental literacy. A design-based research was employed in order to construct the learning program and improve it in consecutive cycles. The findings indicate that junior high school students who were involved in the learning process – through knowledge integration activities, scientific inquiry, and outdoor learning – achieved a meaningful improvement of their cyclic and systemic understanding of the water cycle. The article concludes with a summary of the program's design elements we recommend using in other programs seeking to foster students' understanding of natural cycles within the context of their influence on people's daily lives, rather than in the isolation of their specific scientific domains. It is suggested that an environmentally based science curriculum should involve authentic, real environmental topics, and at the same time, it should emphasize the role of scientific knowledge and skills that are needed for the development of environmental literacy

Keywords: Literacy, Religion, Science, Sociocultural, Superstition

INTRODUCTION

All students (like all citizens) are ‘consumers’ of scientific information in their everyday lives – as they make personal choices (e.g. about health, diet, use of energy resources, etc.) and as they form views on issues affecting society (e.g. waste disposal, genetic modification of organisms, global climate change and CO2 emissions). One aim of science education is to make these ‘consumers’ more intelligent and informed; able to respond in an informed and appropriately critical manner to information they receive (Millar & Osborne, 1998). The publicly aired concerns regarding the environment have influenced educational systems in many western countries. However, educators and researchers from all over the world have pointed out a number of shortages and limitations of environmental education (e.g. Bachiorri, 1995; Benedict, 1999; Gough, 2002; Kuhlemeier et al, 1999; Membiela, 1999; Orion, 2002; Salmon, 2000; Tilbury & Turner, 1997). A review of the literature on this topic indicates that environmental education (EE) in most western countries is still not part of the core science curriculum. Gough (2002) provide a number of reasons why this situation is upheld: the inflexibility of the curriculum, which does not allow teachers plan their own schemes of work; the strong influence of scientists on drafting the curriculums to include their own priorities, which in many cases do not accord with EE priorities; the view

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held by many educators of EE as yet another "pressure" in an already overloaded curriculum; the persistence of some science teachers in teaching their own discipline rather than adopting an interdisciplinary approach; and finally, the superficial understanding of EE commonly held by many of those responsible for the science curriculum. Gough (2002) further asserts that the limiting factor for introducing environmental issues as an integral part of the science curriculum is the extent to which discipline-oriented teachers are able to deal with interdisciplinary subjects.

In recent years, a number of educational packages, which combine sustainability strategies regarding the various aspects of water conservation issues from an interdisciplinary perspective, were developed (D'Agostino et al., 2007; Scoullos, Alampei & Malotidi, 2004). However, of the environmentally-oriented programs that do find their way into the schools, the majority primarily deal with the awareness aspect of environmental education. These programs are not profound enough to further the development of what Orion (2002) termed as environmental insight. Environmental insight is a deeper aspect of environmental education; it includes the understanding that life influences -and is influenced by- the natural environment, and the understanding that the natural environment is a system of interacting natural subsystems, each influencing the others. Mayer (1995) presented the earth systems approach as a venue for science for all education. In the field of earth science education, the environmental aspect is achieving a central position in the overall system. Mayer, (1995), and Orion, (1996) stated that one of the advantages of studying the earth sciences is in the development of environmental awareness and insight. The Earth sciences gives the student - the future citizen - the knowledge and the ability to draw conclusions regarding subjects such as: preservation of energy, economizing on water, proper utilization of global resources. In addition, the teaching of earth sciences may raise the students' consciousness of what is happening around them, in their local environment, in their country, and in the world. Orion (2002) suggested the Earth systems approach as a holistic framework for the science curricula that integrate the earth sciences education together with the environmental education. Therefore, this approach could serve as a powerful platform for understanding the interrelations between life and the physical environment, and for developing environmental insight. The "Blue Planet: The Water Cycle within Earth-Systems" program was developed according to the earth systems approach. The program was constructed through a design-based, spiral model of research, development and implementation; and is designated for the science education of junior high school students'. This research presents the "Blue Planet" program and the design-based research that led to its construction.

RESEARCH APPROACH AND DESIGN

The "Blue Planet" unit's development was supported by a design-based research approach. Design-based research focuses on studying the way the design of a learning environment influences variables relating to known learning and instruction methods (Barab & Squire, 2004; Collins, 1992; Brown, 1992; Shavelson et al., 2003).

The first phase of any design-based research is to examine an initial design, and as the study evolves, to implement certain changes and adjustments according to findings obtained in the data-collection-and-analysis phase. Design-based research must provide a continuous change of design elements, so it will be possible to test and build different learning theories regarding certain environments on the basis of relevant study findings (Collins et al., 2004). The design of successful curriculum materials depends on a process of iterative refinements as a response to the complex systems that impact classroom learning.

The increasing tendency in recent years to conduct design-based research has lead to the development of well established theories regarding the ways of reporting this sort of research. The report should describe all of the different phases of the study, not just its final results. According to Collins (2004), the way of presenting a design-based research should be different than the usual quatrain pattern of background and description of problem; presentation of research tools; findings; and discussion. Collins (2004) suggests five elements for presenting design-based research: a) Goals and elements of design (learning material, activities, designing principals and the interaction between them); b) Setting where implemented (detailed description of changes in the setting during different phases of the study); c) Description of each phase (here all the different phases of the design as well as the changes undertaken for each design should be specifically described); d) Outcomes found (describing the changes of the permanent variables as they took place during design phases); and e) Learned lesson (reference to limitations and successes of the research, both on operation and results levels). In the present research, Collins's presentation guidelines are adopted but are slightly modified, so as to accommodate the needs of the study. The first element is presented and discussed in length in the following section; the remaining elements are organized under the headings of the case descriptions of study 1 and 2.

The design of the curriculum reflects two successive cycles of formative evaluation. The first cycle included about 140 junior high school students (8th grade) from one urban junior high school; the second cycle included about 500 junior high school students (7th-8th grades) from four different urban schools. From the latter research cycle, three 8th grade classes were selected as a case study. As the main purpose of design-based research studies is to improve their design, the amount of success, or lack of success, of every element should be tested. In this study, an emphasis was placed on documenting each of steps of the design improvement process, and therefore, data was collected throughout both cycles of research implementation. In this article we mainly present data relevant for the process of the program's design, especially in regard to the instruction of systems-thinking, on whose implementation there is relatively little research.

As most of the research tools employed in this study were custom made, careful measures were secured for ensuring their validity and reliability. For this purpose, 3 senior earth science researchers assisted in the process of the initial design of the research tools, suggesting improvements and noting shortcomings. As well, a pilot study was conducted with 20 8th grade students (from one of the schools from which a larger sample was later obtained) who studied the unit a year before the main study took place, and after its completion, answered 20 in-depth, open questions as part of a semi-structured interview. In order to enhance the questionnaires' validity the students were asked in this pilot study to write an explanation for each of the statements. This step made it possible to examine whether the students' erroneous replies stemmed from wrong interpretation of the statement's meaning or from cognitive difficulties.. As a result, each of the research tools (to be mentioned later) was refined and later on evaluated further through an expert judgment procedure.

Goals and elements of design

Ben-Zvi Assaraf and Orion (2005) suggest that in order to provide our future citizens with basic tools for knowledgeable dealing with their environment, science education should emphasize studying natural cycles within the context of their influence on people's daily life, rather than in the isolation of their specific scientific domains. This calls for an environmentally-oriented program that not only furthers environmental education toward awareness, but that also helps develop environmental insight and understanding. The "Blue Planet" program is an earth systems-based curriculum package that focuses on the study of water-related issues in an environmental context. The program promotes students' conceptualization of the water cycle as a dynamic, cyclic system. The main goal of the program is to encourage students at the junior high school level to develop systems-thinking as a platform for environmental literacy. For this purpose, we adopted Orion's (2002) tenets for system-based earth science education. Accordingly, the following goals and elements of design of the "Blue Planet" program are presented and discussed: design of the learning environment; the development of the inter-disciplinary scheme; addressing students' need for an authentic learning environment; and the development of environmental insight.

Design of the learning environment

The “"Blue Planet"” program is a 30-hour learning program destined to junior high school students, which was developed to be part of the new Israeli curriculum: "Science and Technology". Within the learning sequence, the "Blue Planet" program is preceded by "The Rock Cycle" program, which focuses on geological processes that transform the materials found within the crust of the earth (discussed in length in Kali, Orion & Eylon, 2003; Orion & Kali, 2005); and as well, follows its pedagogical approach. The manner of designing the activities is derived from the constructivist epistemology, which claims that when students confront new learning material, scientific material included, they use their existing knowledge, beliefs, interests, and goals to interpret the new information; and that this may result in a modification or revision of their previous ideas. In this way, learning proceeds as each individual's conceptual schemes are progressively “reconstructed” as he or she becomes exposed to new experiences and ideas (Palmer, 2005). Palmer further highlights several features that positively impact motivation in constructivist-informed teaching models, these include: teaching techniques for eliciting students' views, providing clear explanations of the scientific viewpoint, carrying out hands-on activities, and applying the learned material to real life.

Following Kali, Orion and Eylon (2003), all of the program's activities are conducted 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 mainly includes questions with a minimal amount of textual information. In this manner, groups of three or four students work collaboratively to "discover" by themselves the hydrological processes.

The development of the interdisciplinary scheme

Interdisciplinary implies the cooperation and integration of the contributing disciplines; the aim being to create a common and single framework shared by all the disciplines involved. The knowledge and methods from the different disciplines go through an alteration and merging process, where each discipline's impact is

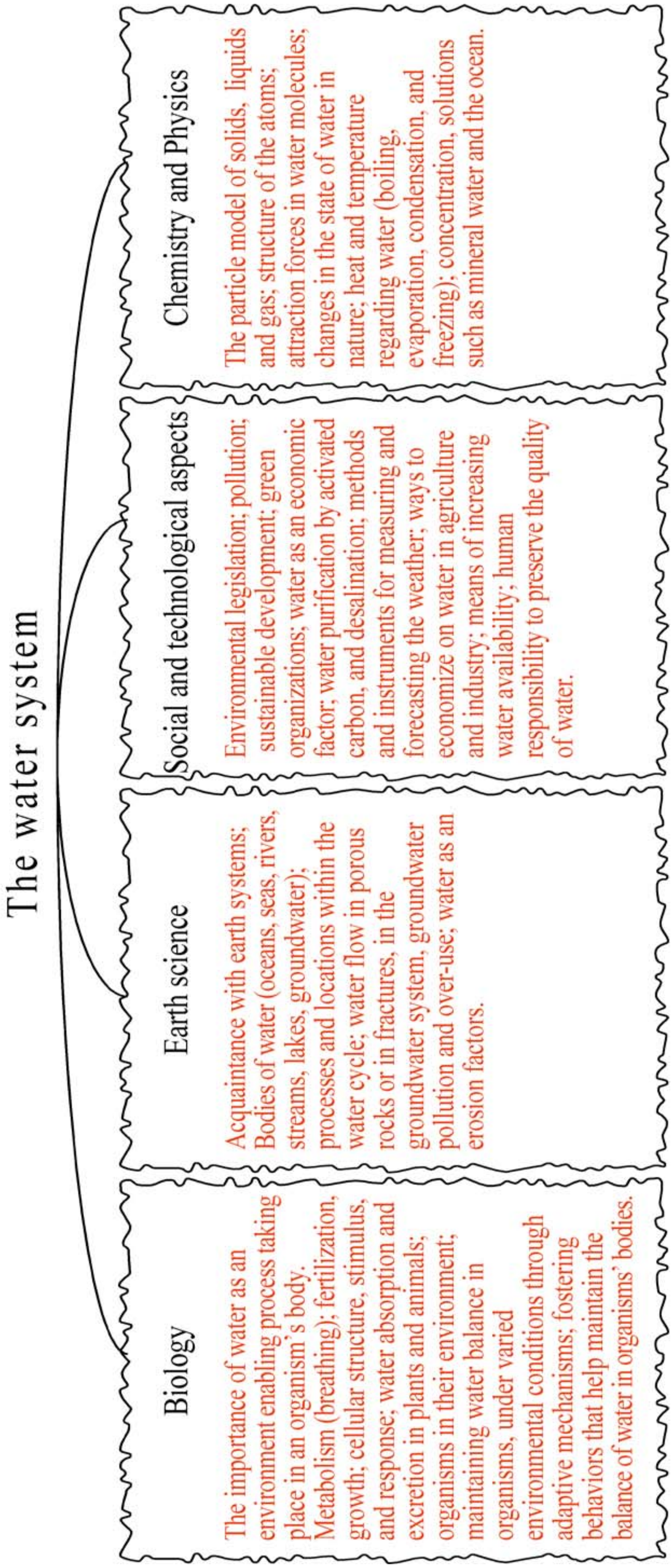

Figure 1. The distribution of water-related contents among the different disciplines of the Israeli junior high school curricula

reduced and it becomes possible for a specific issue to be examined in a systematic way (Scoullos, Alampei, & Malotidi, 2004). However, implementing interdisciplinarity is not without difficulties, recently, Osborne (2007) has claimed that the science education community suffers from the delusion that the offered science learning material must be both broad and balanced; the result being a smattering of all sciences cramming more and more into a limited curriculum. He continues with the plea: "has the time not come to recognize that it is our responsibility to select a few of the major explanatory stories that the sciences offer? And surely it is the quality of the experience, rather than the quantity, which is the determining measure of a good science education?" (op. cit. pg. 175). In this study, the water cycle was selected as the theme or "cover story" of the environmentally-based curriculum development. The reason for choosing the water cycle was because it enables communicating ideas from various knowledge domains, developing environmental insight, and constructing basic scientific knowledge, understanding, and skills. Appendix 1 details the main goals and principles of each of the "Blue Planet" chapters.

The development of a successful interdisciplinary scheme involves the selection of a content area that involves authentic, real environmental topics and at the same time, allows the incorporation of important scientific concepts lying at the heart of the core science curriculum. Water is an obvious content area that fits the above characteristics. This topic is associated with everyday environmental issues such as the quality of drinking water, contamination of ground water supplies, and river pollution. Brody (1995) suggests that the concept of the hydrosphere is one of the most integral concepts related to life and the earth, and thus is critical for achieving an understanding of the complexity and interrelatedness of the earth's systems. As well, the water system can provide a framework for constructing almost any part of the core science curriculum. These include those scientific principles, concepts and skills that are at the base of the major conservative science disciplines – physics, chemistry, geology and biology. Figure 1 below presents the scientific concepts related to the topic of "water" of the Israeli "Science and Technology" curriculum for junior high school. It illustrates a common model for dealing with an interdisciplinary subject (using water as an example).

As part of the curriculum, the water-related concepts in Figure 1 are studied as a set of chapters, each one looking at these concepts through the lenses of a certain scientific discipline; namely, the chemistry of water, the physics of water, water and biology, and water and the earth sciences. Although there are, potentially, numerous links between the different chapters, many students (and some teachers as well) may fail to perceive them because while all the concepts are related to water, relations between the concepts themselves are not clarified within the different chapters. The result is that there is not much of a difference between such "interdisciplinary" programs and the traditional one. Therefore, while developing the "Blue Planet" program, we did not cover the whole range of water-related scientific concepts; rather, we selected only those concepts that were aligned with the program's "cover story". The outline of the program, laid out chapter by chapter with a listing of the various activities, can be found online at http://stwww.weizmann.ac.il/g-earth/blueplanet.

Addressing students' need for an authentic learning environment

For some time now, it has seemed that science learning (especially at ages 14–16) is all too often boring and irrelevant for the majority of the students (Millar & Osborne, 1998). While environmental topics have the potential to arouse interest in science education, in practice, this is not always the case. Water is being an important topic which drives a great interest among Israeli citizens. This interest probably stems of the substantial shortage of water, which is getting worse continuously. Thus, the water might serve as a platform for authentic learning. Brown, Duguid, and Collins (1989) suggest that authentic learning must make information meaningful to the students. It should reflect actual practice that provides authentic contexts that reflect the way the knowledge will be used in real life. However, although the water cycle is strongly related to daily life, especially in Israel which is a semi-arid area, it seems that merely choosing a real-world subject is insufficient for making it relevant in the students' eyes (Ben-Zvi Assaraf & Orion, 2005). Orion (1993) suggested that the main role of using the outdoor learning environment within the learning process is to directly experience concrete phenomena and materials as they appear in the real world. Thus, in order to address the students' need for an authentic learning environment, the whole learning process should be considered in light of its relevancy to the students' actual daily surroundings – their real world. Our conception is that there is no substitute for the real world other than the real world itself. Thus, any curriculum that deals with natural phenomena should, as much as possible, use the outdoors as a learning environment that provides the authentic context for the learning.

Orion (1993) argues that an outdoor learning event should be planned as an integral part of the curriculum rather than as an isolated activity. The "Blue Planet" program adopts this view and implements Orion's (1993) outdoor learning model. As part of the program, the students participate in three field trips in which they explore (a) a polluted river and water treatment plant, (b) a spring and a stalagmite cave, and (c) a winter-rain puddle in their near environment. In each of these sites they conduct the following scientific observations: they explore the earth, rocks and their characteristics, and how they react to water; they compare the water quality in the different locations; they identify the components of the ecological system; they present the interrelationships between earth systems and man; and they raise authentic questions which are later discussed in class. Examples of such questions, actually raised by the students, are: "What are the differences between the tap water that I drink and the mineral water that I buy?"; "What are the properties of the water solution on earth?" and "What influences the groundwater that I eventually drink?". While confronting each of these questions, students learn how scientific knowledge plays a central role in understanding environmental phenomena. Thus, the science class serves as an authentic learning environment. As well, the interaction between the student and the environment outside the classroom results in students perceiving the activities as relevant, and consequently, as interesting.

The development of environmental insight

In order to facilitate the students' development of sound decision-making abilities concerning environmental issues, they first need to develop environmental insight. Such insight is based on an understanding of the systemic and cyclic mechanisms that govern our planet (Orion, 1997). The development of environmental insight is based on the understanding of two main concepts: (a) the systemic perception of the earth - the natural environment - as interacting natural subsystems, and (b) the perception that man plays a role as a part in the natural system. Thus, teaching environmental phenomena regarding the hydrosphere should emphasize the transportation of water within the earth's subsystems and their interrelationships, as derived from the holistic nature of the system. Accordingly, the following three scientific principles were formulated during the program development: The first principle is that dynamic relationships exist between the earth's spheres (biosphere, geosphere, atmosphere, and hydrosphere systems) on the globe; for example, (1) the hydrosphere and geosphere (e.g., chemical dissolution of minerals in seawater, the quality and contamination of groundwater supplies); (2) the hydrosphere and atmosphere (e.g., evaporation and condensation); (3) the hydrosphere, biosphere, and atmosphere (e.g. transpiration). The second principle formulated in the program's development is that the effects of the interaction between the earth's systems result from the energy and substances that pass between and within the systems – biogeochemical cycles. Finally, the third principle is that sustainable development will preserve the capacity of the environment to be a life supporting one. The Johannesburg Declaration on Sustainable Development has suggested that in a sustainable world, society's demand on nature is to be balanced with nature's capacity to meet that demand. Therefore this development should meet the needs of the present without compromising the ability of future generations to meet their own needs (UNESCO, 1997; WCED, 1987).

The ability of students to perceive the hydrosphere as a coherent system depends on both scientific knowledge and cognitive abilities, specifically, cyclic thinking and systems thinking – the ability to perceive the water cycle in the context of its interrelationship with the other earth systems (including Man) (Ben-Zvi Assaraf & Orion, 2005; Kali, Orion, & Eylon, 2003). The "Blue Planet" program emphasizes the development of these cognitive abilities. In order to promote students' construction of the water cycle as a dynamic, cyclic system, the students were engaged in a number of knowledge-integration activities. Such activities include drawings, concept maps, flow charts, and creation of small-group posters, which were conducted in various points of the learning sequence. Figure 2 illustrates one example of a knowledge-integration activity where students used drawings in order to communicate their understanding of complex and abstract concepts regarding the natural environment. In this task the students were instructed to incorporate within their drawings as many items as possible and were assured that they were not expected to perform an artistic drawing. In their drawings they were asked to present their scientific knowledge in a way that emphasizes the water cycle components (stages and processes) and their interrelationships through a network of connections. This framework of connections served as a mechanism by which students could create an entire cycle. In fulfilling these assignments, the students identified the chemical and physical processes that take place within the water resources, such as evaporation, condensation, precipitation, and transpiration, which serve as water transportation mechanisms within the water cycle.

Case description and results: Study one

Participants

The first implementation cycle of the Blue-Planet program included about 140 junior high school students (8th graders) from one urban junior high school. The implementation involved a study aimed at evaluating the influence of learning the "Blue Planet" program on students' perceptions of the water cycle. The two main objectives of the study were (a) to identify junior high school students' previous understanding of the water cycle, and (b) to explore students' perceptions of the cyclic and systemic nature of the water cycle.

Research tools and analysis

The following Likert-type questionnaires, which were distributed before and after the learning sequence, were developed for this study based on categories found in the interviews of the pilot research (see Research approach and design section) and on the relevant literature. For validity purposes, the explanations provided by the students were categorized by relations to unifying statements by three science education senior researchers. Each of the researchers worked individually and only then results were compared. Only categories agreed upon by both researchers were included. For the purpose of content validation, 3 senior earth science educators were presented with a tentative list of the suggested items and were asked to assess their quality, to assign their classification according to the scale, and to suggest items in need of revision. Then, based on the pilot study's findings, we deleted and modified a number of the items. Due to the sample size, no statistical measures for reliability and validity were employed. While the participants were filling the questionnaires, one of the researchers was always present in the classroom to explain the meaning of sentences students found to be unclear. This was important as one of the Likert-type questionnaires' shortcomings is that students which have reading comprehension difficulties may receive lower scores.

Groundwater Dynamic Nature Questionnaire (GDN): This questionnaire was developed for identifying students' ability to identify relationships among the components of the water system (Ben-Zvi Assaraf, & Orion, 2005). To be more specific, it measured students' previous knowledge and understanding of the dynamic nature of the groundwater system, and its environmental relationship with humans. The statements used, sample sizes, and statistical significance – of both pre and post results in the present study and Study 2 (to be described in the next section) – are summarized in Table 1.

Cyclic Thinking Questionnaire (CTQ): This questionnaire was developed to identify students' understanding of the cyclic nature of the hydrosphere and the conservation of matter within the earth systems (Ben-Zvi Assaraf, & Orion, 2005). The McNemar's test (Siegel & Castelan, 1988) was employed in order to check for statistical significance. The statements used, sample sizes, and statistical significance – of both pre and post results in the present study and Study 2 (to be described in the next section) – are summarized in Table 2.

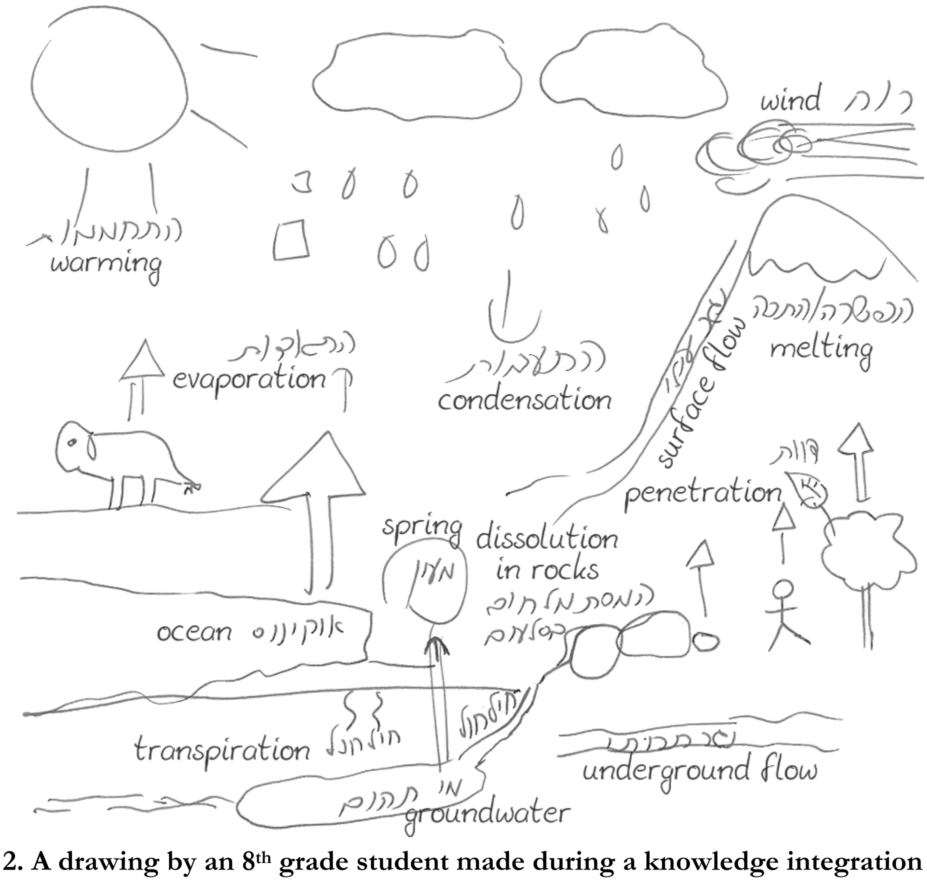

Figure 2. A drawing by an 8th grade student made during a knowledge integration activity.

Table 1. Students' perceptions as shown in a Likert-type questionnaire (GDN), for assessing students' understanding the dynamic nature of the groundwater system and its environmental relationship with humans.

Statements		Level of agreement- Pre			Level of agreement-Post			
S1=Study 1, (N=140). S2= Study 2, (N= 187)		AG %	UC %	NA %	AG %	UC %	NA %	
1. Most of the underground water persists in the small pores of the rock, similarly to a well-watered sponge.	S1	31.8	36.5	31.7	57.1	26.2	16.7	NS
	S2	40	40	20	69.4	16.7	13.9	P<0.01
2. Underground water is similar to underground lakes that are located in spaces inside the soil.	S1	55.9	11.6	32.5	41.8	23.3	34.9	NS
	S2	75	19.4	5.6	58.3	13.9	27.8	0.04
3. Rocks don't influence the composition of water that penetrates them.	S1	14.3	26.2	59.5	14.3	31	54.7	NS
	S2	27.8	30.6	41.7	17.1	14.3	68.6	P<0.01
4. Only when rocks are cracked can water penetrate them.	S1	29.3	29.2	41.5	37.2	14.6	48.2	P<0.01
	S2	13.9	33.3	52.8	19.4	5.6	75	P<0.01
5. Ground water can be found only in rainy areas.	S1	33.3	23.8	42.9	23.3	26.2	50.5	NS
	S2	27.8	50	22.2	13.9	19.4	66.7	P<0.01

AG= agreement , UC= uncertainty, NA= disagreement

Table 2. Students´ perceptions as shown in a Cyclic Thinking Questionnaire (CTQ). A Likert-type questionnaire for assessing student's understanding the cyclic nature of the hydrosphere.

Statements		Level of agreement- Pre			Level of agreement-Post			
S1=Study 1, (N=140). S2= Study 2, (N= 187)		AG %	UC %	NA %	AG %	UC %	NA %	
1. Clouds are the starting point of the water cycle and the tap at home is its end point.	S1	58.3	7.3	34.4	42.8	9.5	47.6	NS
	S2	25.7	51.4	22.9	36.1	8.2	55.7	P<0.01
2. The amount of water in the ocean is growing from day to day because rivers are continually flowing into the ocean.	S1	25.6	30.2	44.2	16.7	28.6	54.7	NS
	S2	11.1	61.1	27.8	16.7	5.6	77.8	P<0.01
3. Amplification of evaporation as an effect of earth global warming may lead to a decrease in the amount of water on earth.	S1	66.6	9.6	23.8	28.5	16.7	54.8	0.03
	S2	47.2	25	27.8	41.7	2.8	55.6	0.04
4. If the population on earth will continue to grow, water consumption will increase, thus decreasing the amount of water on earth.	S1	57.2	21.4	21.4	57.2	11.9	30.9	NS
	S2	63.9	19.4	16.7	45.7	20	34.3	P<0.01
5. Ocean is the starting point of the water cycle and the Ground water is its end point.	S1	50.2	11.7	38.1	33.4	16.6	50	P<0.01
	S2	27.8	47.2	25	20	21.4	58.6	P<0.01

AG= agreement, UC= uncertainty, NA= disagreement

Outcomes found

Transformation of matter within the earth system serves as a basic principle for understanding its dynamic nature. Most of the students had difficulties in perceiving matter (water) transformation within the earth's reservoirs, and to synthesize the water-cycle components into a coherent system. In the water cycle, phenomena such as the quality of ground water and the formation of mineral water stemmed from the interrelationship between rocks and water. Yet, as can be seen in Table 1, after studying the program, only about 50% of the students acknowledged the connection between rocks and water, and perceived the scientific view of the dissolution process as a mechanism by which rocks and water interact (item 3, Table 1). Furthermore, despite students' acquaintance with the evaporation process, they diminished its influence as a mechanism for transferring water from the ocean to the atmosphere (item 2, Table 2).

Learned lesson

Analysis of the research results indicates that in order to develop teaching materials in an environmental interdisciplinary context, it is necessary to take into account the students' cognitive difficulties in understanding their natural environment as a system.

Therefore, the following changes were made in order to improve the teaching sequence in this regard:

a) The revealed difficulty, evidenced by many students, to perceive the underground water in the porous rocks, and to perceive the underground system as a dynamic one, lead to the development of three dimensional models set for simulation of the underground system. The process of modeling engaged students in the scientific practice of using models as tools for observation, exploration, synthesis, and, to a lesser extent, prediction of earth systems and their behavior.

b) The students' difficulty to perceive earth - the natural environment - as interacting natural subsystems required the development of new knowledge-integration activities. For example, Figure 3 presents an 8th grade student's outcome of such an activity, in which he summarizes the inter-connections and transference of matter, after he explored a polluted river, spring, stalagmite cave, and a water treatment plant during a field trip.

c) The students' difficulty to acknowledge their involvement, as human beings, in environmental aspects, such as water pollution, sewage, and water consumption, lead to the development of workshops that facilitated the development of environmental perception.. An example of an activity designed to develop environmental participatory decision-making abilities is the factory assignment. In the factory assignment the students were told about a chemicals factory that is planned to be built in their town. The students were provided with a list of experts in the fields of geology, economy, environment, hydrology and chemistry. They were required to ask each expert three questions in order to decide whether they would recommend building the factory. In addition, the students elaborated on their questions and explained, for each question, why they thought it was important and relevant to the assignment. The use of such participatory decision-making processes is necessary for educating for sustainable development since, it is value-driven and the expected norms are made explicit in order to be examined, debated, tested and applied (Springett & Kearins, 2005).

Case description and results: Study two

Participants

The second implementation cycle was conducted with about 500 junior high school students (7th-8th grades) from four different urban schools. Three 8th grade classes from two urban schools were selected from this population for a case study. The case study deals with the development of systems-thinking skills at the junior high school level. The sample of the current study includes 70 junior high school students (8th grade) from three classes in two different schools. These specific classes were selected because their teachers were

In the field trip you were exposed to processes of transportation of matter between the earth systems participitating in the water cycle. Write in the table examples of those processes that you observed in the field trip.

The matter	Transport from the sub-earth system	To the sub earth system	Throughout the process of
Rain	Atmosphere (clouds)	Geosphere (earth's crust)	Penetration
Calcite ($CaCO_3^-$)	Geosphere (limestone rocks)	Hydrosphere (groundwater)	Dissolution
Ions of Calcite	Hydrosphere (groundwater)	Geosphere (stalagmite cave)	Sedimentation
Water	Hydrosphere (groundwater)	Biosphere (plant roots)	Absorption
Chemicals	Hydrosphere (rivers)	Hydrosphere (groundwater)	Penetration
Water	Hydrosphere (groundwater)	Hydrosphere (spring)	Underground flow
Sewage	Biosphere (humans and man-made environment)	Hydrosphere (rivers)	Surface flow

Figure 3. An outcome of a knowledge integration activity of an 8th grade student following an outdoor learning activity involving a spring, a stalagmite cave, a polluted river, and a water treatment plant.

willing to participate in a professional development course regarding the "Blue Planet" program and because they agreed to one of the author's observation of all the classes. The objectives of this study was twofold: (a) to identify the higher-order thinking skills that were involved in the systems thinking process; and (b) to evaluate the influence of learning the “"Blue Planet"” program on the development of systems thinking of junior high school students.

Research tools

Data for this study was obtained through a series of quantitative and qualitative research tools. We re-administered the GDN and CTQ questionnaires mentioned above to determine whether the changes we have made yielded improved results, and we added a further research tool – drawings of the water cycle in nature with captions explaining the processes – in order to arrive at a more qualitative view of the students' grasp of the cyclic and systemic nature of the water cycle. It is important to note that this second cycle of testing was conducted in the same school as before and with classes of the same level and with the same teachers.

<u>Students' drawings</u> - Students’ drawings can serve as “windows” to children’s conceptual knowledge. They are one of several meaningful tools that can be employed to assess scientific conceptual knowledge, observational skills, and the ability to reason (Dove, Everett, & Preece, 1999; Rennie, & Jarvis, 1995; White, & Gunstone, 1992). In this study, the students were asked to draw, both before and after the learning sequence, "what happens to the water in nature"? The students were assured that they were not expected to perform an artistic drawing and were instructed to incorporate as many items as they could in their drawings. No resistance to performing the drawing assignment was observed among the participants.

The students' drawings were analyzed using Rennie and Jarvis's (1995) coding framework. Within this framework, researchers determine the appearance frequencies of certain pre-defined elements in order to arrive at a vista of the conceptual model of the participants regarding the topic under investigation. The elements can be represented pictorially and/or verbally by captions. In order to increase reliability and consistency of the analysis procedure, both authors of the present study coded the drawings individually, and only after comparing and discussing their analyses, developed a standardized coding system. As a result of this procedure, the following criteria were finally arrived at: (a) the appearance of the earth systems; (b) the appearance of processes; (c) the appearance of human consumption or pollution, and (d) cyclic perception of the water cycle according to the connection point among the water cycle components.

Outcomes found

The analysis of the GDN and CTQ tools reveal that the program's effectiveness in regard to the students' ability to identify dynamic relationships within the system (GDN), and cyclic thinking (CTQ) improved. Tables 1 and 2, 3 show that items in which the changes between the pre and post test were not significant (NS) in study 1, were significant in study 2 ($P<0.01$). This is especially evident in item 5 in Table 1, “Ground water could be found only in rainy areas”, where in study 1 the students' improvement between the pre and post tests was statistically insignificant, while in study 2, the students improved their answers from 22.9% in the pre-test to 66.7% in the post-test.

There is an interesting finding in regard to items 1 and 2 of the GDN (in table 1). In fact, these two statements are contradictory. Either most of the underground water persists in small pores of rock (item 1) or in underground lakes. However, our findings indicate that while in item 1 in the post- test of study 2, 70% of the students presented a scientifically correct model of underground water movement through porous rock (in relation to 40% in the pre test); in parallel, in regard to item 2 in study 2, 58% of the students described the groundwater as a static, sub-surface lake. This finding is strengthened by the analysis of the drawings, in which about a third of the students who included ground water in their drawing also evidenced this contradictory phenomenon. An example of this can be seen in Figure 4. We will further discuss this phenomenon in the Learned lesson section.

Analysis of the students' drawings before the learning process indicates that significant improvements took place between the pre and post tests. Table 3 summarizes the distribution of the water-cycle processes indicated by the students both verbally and pictorially, before and after the learning sequence.

As can be seen in Table 3, in the pretest, students who drew the water cycle usually represented the upper half (i.e. evaporation, condensation and rainfall) and ignored the ground water system. More than 50% of the students did not identify components of the ground water system even in cases where they were familiar with the associated terminology. The post-learning drawings revealed that most of the students increased their acquaintance with the components and processes of the water cycle significantly. For example, 90% of the students incorporated the penetration of rain within the soil and rocks in their post-learning drawings. In the water cycle, phenomena such as the quality of ground water and the formation of mineral water stem from the interrelationship between rocks and water. Yet, before studying the program, only 30% of the students acknowledged in their drawings the connection between the composition of the water solution and the rocks that

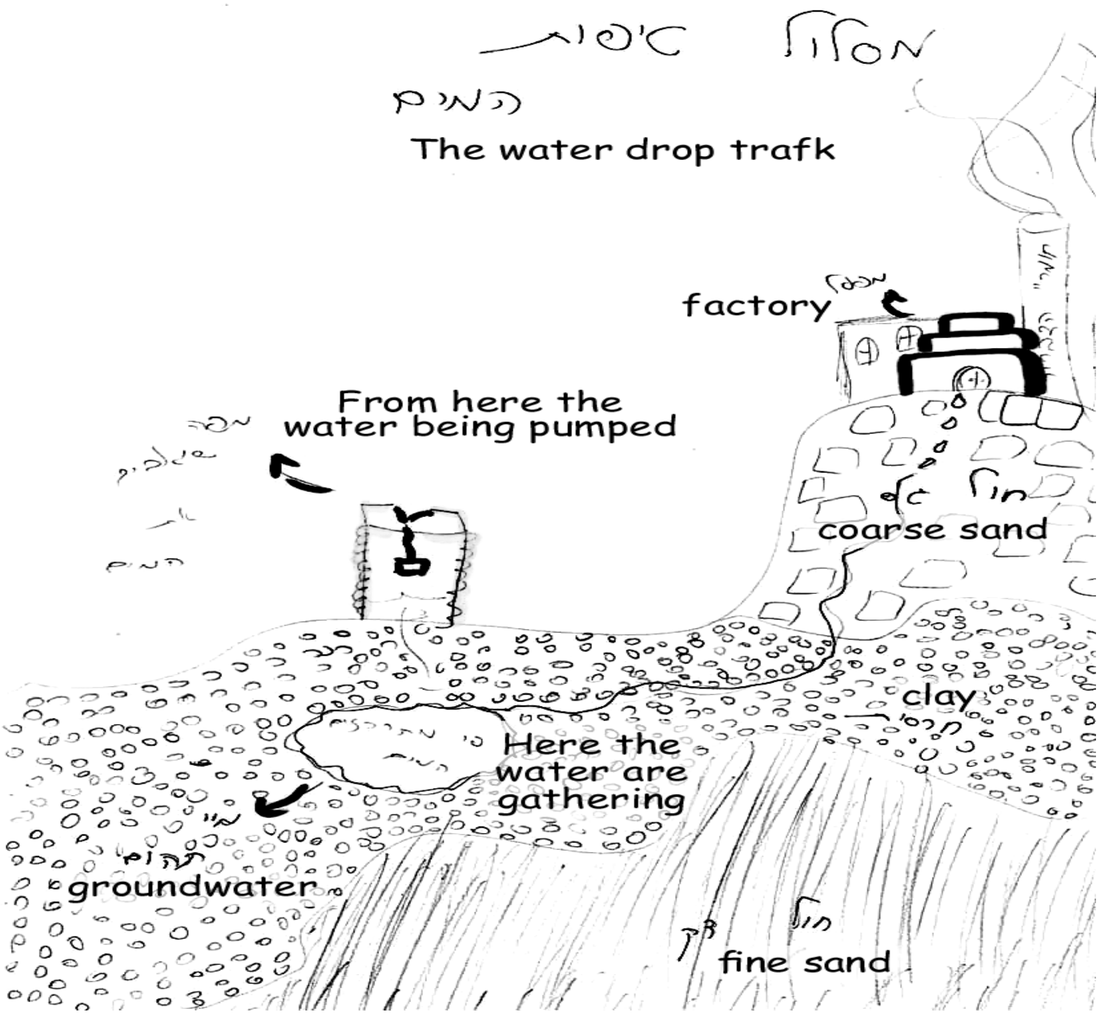

Figure 4: Student drawing evidencing both scientific and non-scientific models of water underground movement.

they passed through. After studying the program, about 70% of the students acknowledged the connection between rocks and water. Consequently, about 37% of the students presented in their post-learning drawings a connection through the rivers, through underground water flow or transpiration, compared to 3.7% of them in the pre-learning ones.

To sum, the drawings' analysis indicates that most of the students had significantly shifted from a fragmented perception of the water cycle to a more holistic view of the water cycle. However, it is important to mention that many students still presented difficulties in understanding the hidden processes that demonstrate the cyclic nature of the system. This can also be viewed in the CTQ post test results study 2, where about 40% of the students still did not realize that in a cyclic process the overall amount of matter is being conserved (Table 2, items: 1, 5). Another disturbing result, is the absence of Man in the conceptual models represented by the drawings. Only 15.3% noted pollution and only 20.92% noted water consumption in their drawings (items 12 and 13 respectively, in Table 3)

Learned lesson

In general, study 2 revealed that junior high school students could focus on recognizing the inter-connections between the parts of a system and then synthesize them into a unified view of the whole. Students who were involved in the learning process – through knowledge integration activities, scientific inquiry, and outdoor learning – achieved now a meaningful improvement of their cyclic and systemic understanding of the water cycle.

This last statement is not clear. Do you want to say that therefore a number of changes were incorporated into the curriculum based on the outcomes of Study Two?

In regard to the parallel conflicting scientific and non-scientific conceptions regarding how water was stored underground, it is important to mention other conceptual change studies suggesting that the shifting to the scientific model does not happen in a replacement fashion, but rather occurs in parallel (Marques and

Table 3: Student perceptions of the water cycle as shown in their pre and post drawings (McNemar's test) n=220

A – Process within the water cycle	Pre (%)	Post (%)	M - value	P - value
1. Evaporation	94.59	97.3	0.33	NS
2. Condensation	62.16	70.27	0.69	NS
3. Precipitation	100	98.1	1.1	NS
4. Penetration	67.57	94.59	8.33	0.004
5. Underground flow	10.81	59.46	16.2	0.001
6. Surface flow	37.8	59.46	4.57	0.033
7. Melting	0	27.03	-	0.01
8. Freezing	0	5.41	-	NS
9. Dissolution	0	21.6	-	0.01
10. Transpiration	0	24.9	-	0.001
11. Capillarity	0	29.73	-	0.001
12. Pollution	0	15.3	-	0.012
13. Water consumption by man	13.5	20.92	0.5	NS

Thompson, 1997). In regard to groundwater, Libarkin et al, (2005) and Libarkin and Kurdziel (2006), found that university students evidence both scientific and non-scientific models. Nevertheless, in order to try and facilitate this, apparently robust, conceptual change, we added an outdoor learning activity in which students explored a modern well which supplies water to their city. In this activity, the students saw that the well model (developed as a result of study 1) was indeed a reflection of real wells, where there were no underground lakes even as far as 200 meters down.

This statement is also confusing. Consider rearranging it as: Man's involvement in the water cycle, as mentioned above, was largely ignored by many of the students.

In other words, the preservation of underground water quality and water reservoirs seemed irrelevant issues from the perspective of their daily life experience. To rectify this situation we decided, in accordance with Linn & Hsi (2000), to structure the interdisciplinary learning unit around authentic questions that directly relate to environmental phenomena that students can interact with. We integrated Linn and Hsi's approach with the "Explanatory stories" approach suggested by Millar and Osborne (1998). This latter one emphasizes that understanding is not concerned with individual propositions or concepts, but rather with inter-related sets of ideas that provide a framework for the understanding. Therefore, a crucial step in our model was to identify a current, ongoing environmental challenge frequently talked about and debated in the Israeli media. This topic – water availability and quality – was then utilized as an environmental "cover story" to head the cross-curricular learning process. Figure 5 illustrates our model for dealing with an interdisciplinary subject such as the hydrosphere.

As can be seen, the sequencing of the authentic questions constitutes a cover story which provides smooth passage from one chapter to another and from one discipline to another throughout the book. Our model tries to distinguish between the curriculum developers' goals and the students' needs. For example, for us, curriculum developers, the main objective of the ""Blue Planet"" program was to develop environmental insight through the development of students' cyclic and systems thinking abilities. However, for the students, we had to find a relevant question that would motivate them to become involved with the learning process. For example, "Will we have enough drinking water forever?" This question raises a series of questions such as: Where can we find water on earth? What influences the water quality? While confronting such secondary questions, students learn basic core curriculum scientific knowledge. For instance, in order to answer the question "What is the relationship between life and water?" students construct concepts such as metabolism (breathing), fertilization, growth, cellular structure, and stimulus and response. It is suggested that in order to determine the availability of water resources for humans, students could explore the distribution of water on Earth. For example, while dealing with the question "How did the oceans become salty?" the students learned some chemistry-based concepts such as dissolution and evaporation, particles, water molecules and compounds, and the concentration of ions. While dealing with these concepts, in inquiry-based programs, the students begin to understand the meaning of some of the most basic concepts used in scientific methodology for an independent inquiry process. Such an understanding provides them with the means for making hypotheses, designing experiments, collecting and analyzing data, and reporting their findings. Moreover, they learn how to use higher-order learning skills and how to apply scientific methodology for making their own investigations.

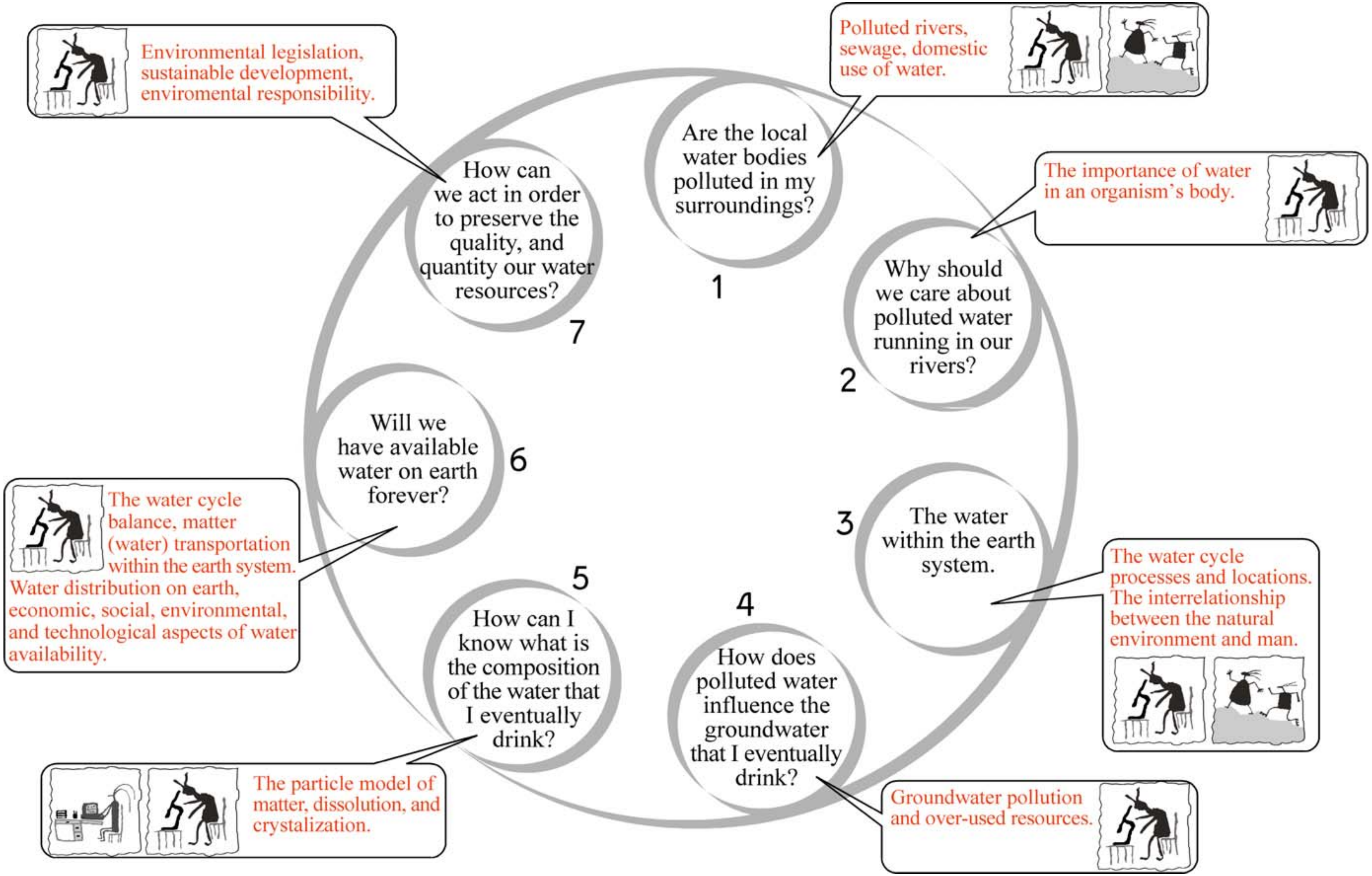

Figure5.A model of the program's learning sequence. In the circles: the authentic questions that "move" the "story" from one chapter to another. The boxed external remarks: the main concepts, which are discussed in the various chapters. The boxed icons: the various learning environments that are involved in the learning process (lab, outdoors and computer).

Based on the collected data, it was possible to revise the curriculum materials into its final form consisting of a workbook: "The Blue Planet – the water cycle within the earth systems", a field workbook, and a project guidebook, that is available at (http://stwww.weizmann.ac.il/g-earth/blueplanet).

SUMMARY AND DISCUSSION

This study presented a spiral, designed-based research, which aimed at developing a meaningful learning experience that would lead to the development of environmental insight among junior high school students. The improved learning outcomes and program design suggest that the model presented here for development and implementation of an interdisciplinary environmental program within the science curriculum is promising, and that the learning programs resulting through such design procedures have a high potential of being successful. A summary of "Blue Planet" program design elements follows. We recommend using them in other programs seeking to foster students' understanding of natural cycles within the context of their influence on people's daily life, rather than in the isolation of their specific scientific domains.

The Blue Planet program presents a "cover story" about the water cycle on Earth. The choice of stories should balance between several factors. On the one hand, the breadth of the scientific knowledge requires a selection of the subjects that the curriculum will employ. On the other hand, the curriculum should leave sufficient time for discussion, thinking and analysis. For example, using knowledge integration activities, students were able to connect and integrate knowledge acquired in school with components of the earth systems observed in the field trip. Thus, the students confronted their difficulties in identifying the system components; created relationships among the components and organized and placed them within a framework of relationships. Consequently, they were able to develop high-order thinking skills such as systems thinking and environmental insight.

It was attempted to design a learning environment that on the one hand, presents an interdisciplinary scheme for presenting the scientific mechanisms underlying natural phenomena, and on the other hand, presents a learning program that focuses on relevant environmental topics in the students' immediate environment. Many programs and researchers call for structuring science curriculums so as to connect them to students' lives. Calls for using "authentic tasks" making science "relevant", promoting community connections, and building from local contexts are common features in today's science education reform initiatives (Dillon, 2003; Palmer, 2005; Rivet & Krajcik, 2008). Furthermore, it is not sufficient for the problems only to be of interest to the students. A necessary characteristic for relevancy is that the problems should be meaningful and provide a need-to-know situation to learn specific scientific ideas and concepts (Rivet and Krajcik, 2008).

This sentence is not clear. Consider re-writing as: The fact that the student selects the task and conducts within small working groups, with the teacher acting as a moderator of enthusiasm and interest is, undoubtedly, essential for the learning process (Palmer, 2005).

The role of the teacher is to mediate between the students and scientific knowledge, by helping students use the inquiry method to investigate the Earth and its processes (Kali, Orion & Eylon, 2003). One of the main barriers for the success of the "Blue Planet" program was the lack of teachers' willingness to get out and teach in an outdoor learning environment. They preferred to remain in their usual settings of the laboratory. Braund and Reiss (2006) explain that, since teaching within a laboratory becomes part of teachers' professional identity (reinforced, we suspect), laboratory-produced knowledge is seen as having higher worth than other sorts of knowledge. It is suggested that the teachers' positive experiences with teaching an environmentally based program outdoors may help in altering their professional identity and consequently play a central role in their motivation to adopt an interdisciplinary approach. Hopefully, this will result in the teachers' becoming fine models of enthusiasm and interest.

Regarding interdisciplinary, understanding nature's phenomena is not possible without an interdisciplinary outlook, and this outlook can only be developed in the real world; in the natural environment. In order to maximize the cognitive benefit of school trips, DeWitt & Osborne (2007) suggest that they should be conducted in the following manner: teachers should be encouraged to become familiar with the setting before the trip; to orient students to the setting and agenda and clarify learning objectives; to plan pre-visit activities aligned with curriculum goals; to allow students time to explore and discover during the visit; to plan activities that support the curriculum and also take advantage of the uniqueness of the setting; and to plan and conduct post-visit classroom activities to reinforce the school trip experiences (p.686). These suggestions are in line with the manner in which the fieldtrips in the present research were conducted (detailed in Orion, 1993). However, in order to allow the outdoor learning environment to become an integral part of the learning sequence in environmental education, the way students learn from direct and concrete experiences, in a real and relevant environment should be further explored.

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