

A *Thinking Journey* Based on Constructivism and Mediated Learning Experience as a Vehicle for Teaching Science to Low Functioning Students and Enhancing their Cognitive Skills

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ABSTRACT An Experimental Astronomy Curriculum or *Thinking Journey* was developed on the basis of a combination of Constructivism and Mediated Learning Experience (MLE). The *Thinking Journey* was designed to serve as a vehicle for promoting a process of conceptual change in a wide range of students. Its theoretical background, curriculum and an experiment to test its effectiveness with a class of low functioning high school girls are documented here. The study included an experimental (E) and control (C) group, each of which comprised 16 9th grade students. E focused on the concept of Earth within the framework of the *Thinking Journey*, while C was exposed to the conventional approach to the study of Earth within the Earth Studies curriculum. The results indicated the relative effectiveness of the *Thinking Journey* in promoting a process of positive change in the students' conceptualization of Earth, improving their knowledge of astronomy, enhancing their general scientific knowledge and developing their cognitive functioning and problem solving abilities. These findings are discussed in terms of the usefulness of utilizing a scientific subject as part of an educational intervention designed to enhance the cognitive abilities of low functioning students.

Introduction

'One thousand two thousand'. No, it is not the count of the millennium, but the count of the number of meteors that students saw on November 18th 1999. All the students of the school sat on the school's lawn from

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11 pm to 5 am to watch the very special Leonide's meteors' shower. They saw thousands of meteors, and were reluctant to leave school, even in the morning. These were not students at a special school for gifted children, or a science academy. They were at a school for low functioning students where an experimental astronomy program has been implemented in the last seven years.

How can one explain the reasoning of a director of a school who chose to teach astronomy to a class of low functioning students at a junior-high school? There are so many prerequisites for learning astronomy that perhaps one should put it at the end of the line. However, think of the possibility that these students will be able to demonstrate that they really can learn and succeed in astronomy. Perhaps one could even use astronomy to enhance the students' cognitive skills and to foster their feelings of competence.

At the end of each year of learning astronomy the students worked on astronomy projects. They wrote about astronomy topics that they had not learnt in the classroom. They lectured to their teachers and parents, who were surprised to listen to talks on astronomy given by these particular students. When significant others look at the students in a more positive light, it can lead to an enhancement in their feelings of competence.

The fact that these students spent so much time watching these celestial special events and were involved in lecturing on interesting projects, illustrates the possible effects of a process and experience that motivated the students. This process resulted in students being motivated to learn interesting subject matter, even when it seemed complicated beyond their assumed learning ability. This process and experience represent the focus of this article.

The relevance of constructing an experimental astronomy curriculum that would be of interest to these students requires a consideration of its theoretical background. The curriculum was in fact based on a combination of the Constructivist and the MLE approaches.

On this basis, the Experimental Astronomy Curriculum (EAC; Schur, 1998) was developed with a group of low-functioning students in the 9th grade of a public school in Jerusalem. The EAC, which was specially developed to relate to the abilities/characteristics of the students, used a pictorial language of communication and linked classroom and everyday experiences. After its completion and a successful experiment to test its effectiveness, the EAC was adopted as part of the Israeli national science curriculum for junior-high schools.

This article presents the theoretical background of the EAC and documents the experiment to test its effectiveness.

Constructivism and MLE as the basis for an astronomy curriculum

The constructivist approach to science teaching

Constructivism addresses the question: how does a person come to know, come to understand? The Constructivist answer is that a child constructs her ideas of the world, and this is her knowledge and the meaning is determined by her. Following Piaget, students' knowledge and their ideas about science are often very different from the teachers'. Research since the 1970s has conclusively shown that children construct considerable knowledge about the natural and technological world from their interactions (physical and social) in the world. Because these ideas are often at variance with current scientific theory, implications for learning and teaching in school are obvious.

In addition, many studies show that children come to the teaching of science with their alternative ideas, and that although they pass tests and exams, they still hold on to their alternative ideas. The challenge has thus become to develop instructional environments where real changes in students' firmly held intuitive ideas could be facilitated.

The Constructivist approach to science teaching relates to the way children understand scientific concepts. The teacher has to listen to the alternative concepts of his students, which is the way they conceive of the scientific concepts that are being taught in the classroom. Constructivism defines learning as a conceptual change from the student's initial concept towards the scientific one (Driver and Oldham, 1985). Thus, the learner is supposed to be able to distance herself from her initial concept through a process of examining different alternatives.

Teaching toward conceptual change adds an important dimension to science education. The aim of the science lesson is focused on subjects that relate to the students' everyday reality. The science lesson is no longer a one-way transmission of knowledge, but rather is expected to establish long-term dialogue between the teacher and students and to elicit from the students their own construction of their concepts. The teacher acts as a mediator between scientific knowledge and the alternative concepts of the students. The goal of this interaction is to enable the students to change their concepts and to approach the scientific ones. Accordingly, appropriate subjects must be chosen for the science class that relate to concepts that are more comprehensive than the mere accumulation of scientific knowledge.

Enabling students to embark on a process of conceptual change is not an easy task. Howe (1996), Strauss (1987) and Vygotsky (1986) note the importance of linking the conceptual development to the learners' everyday experience. One may expect to encounter some difficulties as learners refuse to abandon initial concepts that have formed part of their

everyday perception for years. It is not only necessary to explain clearly the scientific properties of the concept, but also to connect it to the learners' everyday perceptions.

The science teacher is expected to relate to the students' initial concepts as an important factor in his teaching. In order to enable his students to modify their concepts, he must also understand and address the change processes they experience.

Science teaching and the construct of MLE

The construct of MLE – central to the theory of Structural Cognitive Modifiability (SCM; Feuerstein 1979; 1980; 1988) – can give direction to the teaching of science and its application to the enhancement of cognitive skills. For Feuerstein et al. (1988), the basic characteristic of a human being is his/her modifiability. A student who is labelled 'weak' in the classroom will not necessarily remain at her initial level of functioning. Change is possible not only in the quantity of her knowledge, but also in the quality of her interaction with the environment. In terms of the theory of SCM, it is not expected that such change will occur by itself. The teacher must actively enable the student to experience such change, by giving her the tools to benefit from the current interaction in future interactions too.

Mediation is an important component of the development of the individual's ability to interact with her environment. MLE relates learning to particular characteristics of the learner's environment. In order to survive in a rapidly-changing environment, the individual must be autoplasic; that is, she must be capable of changing herself according to the needs of her fight for survival. Thus, Feuerstein et al. (1980: p. 3) state that 'The survival of any organism depends on its ability to adapt. For the human organism, successful adaptation involves the ability to respond not only to a constant and stable environment but to situations and circumstances that are constantly changing'.

The need to adapt to the environment demands cognitive modifiability and flexibility. MLE is the key to such modifiability, which enables the human being to adapt to the environment. If the individual learns how to learn from her experiences, then she will be able to benefit from them. Learning how to learn in a specific context depends on the cognitive prerequisites that are relevant to the specific learning task. Cognitive processes, which are developed through appropriate MLE, are important for the individual to be able to benefit from learning tasks with which she is confronted. 'Modifiability is directly determined by the quality of interaction between the organism and the environment which becomes possible only by MLE' (Feuerstein and Feuerstein, 1991: p. 13). The task of the teacher as a mediator is to set learning tasks that will act as changing environments in the classroom and to systematically give the

learner the cognitive prerequisites that are necessary in order for her to successfully tackle the learning tasks.

The construct of MLE is both explanatory and prescriptive. It explains the basis for the development of learning potential in human beings, which relates to the extent to which their own culture has been mediated to them. It also provides the guidelines for intervention between a parent/teacher and a learner and for intervention at different stages of the individual's life. MLE focuses on the relationship between the human being and her environment. Although it was not developed in the context of science education, Feuerstein quite often addresses the issue of the interaction between children and their environment in scientific contexts (Feuerstein, 1998: pp. 31–42). The construct of MLE is compatible with the notion of a scientific interaction with the environment as a means of developing cognitive skills of students.

The MLE approach promotes the focus in science teaching on the interrelationships between students and their environment, with the active participation of their teacher in the process. Mediated interactions demand that both the teacher and the students play an active role (Mehl, 1985; 1991; Strang and Shayer, 1993). Feuerstein et al. (1988, Chapter 4) devote an entire chapter of their book to demonstrating a mother's role in enhancing the ability of her children to observe scientific phenomena in the context of a science museum. This leads to the notion that one can enhance the cognitive skills of students by mediating their interactions with their natural environment. In other words, one can use science teaching as a means of enhancing the ability of students to observe their environments. Thus, MLE could lead to the development of various cognitive functions or skills. The constructs of MLE and cognitive functions are further defined in the sections that follow.

The parameters of MLE

Feuerstein and his associates (Feuerstein et al., 1979; 1980; 1988; 1991) define twelve specific criteria or parameters of mediated interactions. Three of these are basic and essential to the characterization of an interaction as a *mediated* interaction. They include the following: *Intentionality and Reciprocity*, *Transcendence* and *Meaning*. These are defined as follows:

Intentionality and reciprocity – The most important difference between a mediated and nonmediated interaction lies in the fact that MLE is marked by an intention animating the mediator, as she interposes herself between the child and the sources of the stimuli. MLE encourages the child to perceive things with clarity and precision. The mediator transforms the stimulus, rendering it more salient and attractive to the

child. Furthermore, the mediator will change the set of the child, rendering her more vigilant and positioning her so that she is more ready to attend to the stimulus and thus reciprocate the mediator's intention. In the process, the mediator also changes herself, becoming more attentive to the child and understanding the environment according to the child's view of it.

Transcendence – An MLE interaction is never limited to the immediate need that elicited it. The mediation goes beyond the 'here and now' of the interaction. The same cognitive processes that were involved in an interaction relating to a specific content can be used in a wide variety of other contexts. It is the transcendent nature of the interaction that produces flexibility in the child's thinking. Transcendence allows the child to distance herself from any specific stimulus. The child acquires the cognitive prerequisites that enable her to act upon the environment in increasing distances of time and space and levels of abstraction.

Meaning – The mediation of meaning involves the communication by the mediator of the value and/or relevance of particular stimuli or content. *Meaning* represents the energetic, emotional power that makes it possible for the mediational interaction to overcome resistance on the part of the learner and thereby ensure that stimuli mediated will indeed be experienced by the learner. The mediation of meaning ensures that the child not only becomes receptive to the world but also is engaged in a mutual and reciprocal interaction with it.

The three basic parameters are of a universal nature. These parameters enable human beings to become more flexible in their interactions with their environments. Feuerstein et al. (1979; 1980; 1988; 1991) discuss nine other parameters of MLE that are task dependent and related to the culture to which one belongs.

Cognitive functions

Feuerstein et al. (1979; 1980; 1988) have also defined the cognitive processes that are involved in human interaction and thinking and which can be enhanced through effective mediation. Specific cognitive functions and deficiencies are identified within the framework of 'three phases of the mental act', namely, 'input', 'elaboration' and 'output'. These cognitive functions and deficiencies provide a means for understanding an individual's process of cognitive functioning and for diagnosing deficiencies therein. Thus, the cognitive dysfunctions that impair an individual's ability to receive mediation, and those that require mediation, can be identified. Four out of Feuerstein's list of 29 cognitive functions, are elaborated in the following paragraph in terms of the description of them by Feuerstein et al. (1980: pp. 85–103).

Conservation of constancies – Perceptual stability is dependent on the capacity of the individual to conserve the constancy of objects across variations in some of their attributes and dimensions. The lack of conservation of constancy is manifested in a limited disposition to conceive categories of objects above and beyond differences between them because of the lack of readiness on the part of the learner to accept a common factor as constant and to abstract this common factor from other dimensions on which the objects may differ. Thus, the phenomenon of the conservation of constancy can explain the difficulties experienced by the child on a conceptual level in producing proper superordinate concepts.

Use of two or more sources of information – The lack of disposition to use two sources of information at the input level is a phenomenon observed in many situations and accounts for much of the unsuccessful performance of children on psychometric tests and in particular academic and everyday life situations. If the individual is not oriented to gathering all the data from various sources, but rather satisfies himself with only one source, then the input is inadequate and his functioning will be limited to the simple identification or recognition of perceived elements.

Projecting virtual relationships – Deficiencies in projecting virtual relationships are concerned with those relationships that have been established and grasped but have not yet been applied in the handling of new situations. The relationships exist ‘virtually’ in the individual but remain to be projected into a specific constellation of objects and events. Thus, this deficiency involves the need to restructure a given constellation and then to shift from one type of relationship to another as required by new tasks confronting the individual.

Continuous vs. episodic grasp of reality – Grasping the world episodically means that each objective event is experienced in isolation, without any attempt to relate or link it to previous or anticipated experiences in space and time. An episodic grasp of reality reflects a passive attitude toward one’s experiences because no attempt is made by the individual to actively contribute to his experience by organizing, ordering, summing or comparing events and thereby placing them within a broader and more meaningful context.

The application and mediation of these four cognitive functions within the intervention program of this study, is described in the relevant section below.

The combination of Constructivism and MLE as a basis for science teaching

The Constructivist and the MLE approaches both relate to processes of

change. The Constructivist approach addresses the factors that influence the student's initial concepts and deals with the process of conceptual change, while the MLE construct is concerned with the cognitive processes that are needed in the interrelations between the human being and her environment. The Constructivist approach determines the expected course of development of a concept in the student's mind. The MLE approach identifies the variety of thinking paths that a student may take in the course of the development of the concept and promotes the student's ability to reorganize accordingly the way she observes different environments.

The combination of these approaches enables the use of focused mediation which relates specifically to the position of the students vis-a-vis the concept. This combination also allows the use of flexible mediation that takes cognisance of the variety of thinking processes that can be used in the process of conceptual change. Further, it promotes a reorientation in the learner's relationship with her environment which enables her to observe it from a different perspective.

The Constructivist approach to science teaching is based on the emphasis placed by Piaget upon the constructivist nature of the learning process. It makes the assumption that, from birth, individuals are actively involved in constructing their own personal understanding from their experiences. They construct meanings of events and phenomena as part of their attempt to make sense of the world. They base their conceptions on their direct experience with the physical world (Driver and Oldham, 1985; Williams and Burden, 1997).

Teaching science, according to the Constructivist approach, views learning as the reorganization and development of students' conceptions. This demands the consideration in science teaching of the alternative concepts that learners have constructed and promotes the active construction of meaning on their part (Driver and Oldham, 1985).

The MLE approach to science teaching is based upon Feuerstein's view of the human being as a changing entity, who is constantly learning how to survive in the various environments that she encounters during her life. Learning science or any other subject matter is viewed as an interaction between an individual and an external environment that demands that this individual modify herself. Her ability to tackle the demands of her learning environment can be enhanced by experiencing mediated interactions. These interactions focus on the relevant cognitive processes. Feuerstein's assumption is that through the enhancement of cognitive functioning the learner will improve her performance in subject matter learning (Feuerstein et al., 1980; Feuerstein et al., 1997). One has to identify the relevant cognitive processes involved in the learning of scientific subject matter and design the mediated interactions and enhancement of these cognitive functions around this

scientific context. Then, the cognitive processes developed through these mediated interactions can be generalized to enable students to learn other areas of content.

The Constructivist approach places considerable demands on the science teacher. This article argues that the combination of the Constructivist approach and Feuerstein's MLE approach can be beneficial to the science teacher. The Constructivists offer a map of what should be achieved in the science class, while MLE describes a process enabling movement from one place to another on this map and relates it to the environment. In order to provide a clearer understanding of the combination between the Constructivist and the MLE approaches to science teaching, one can relate to the descriptions of the learning process given by Driver and her associates and by Feuerstein and his collaborators.

The description of Driver et al. (1985) of the learning process starts with a piece of information that enters the mind. The question that is posed is whether and to what extent this information will affect the existing concept in the child's mind. The piece of information can remain completely isolated and have no effect on the existing schemas of the mind. The second possibility is that it can exert a partial influence. It can affect some parts of the mind's schemas. The third possibility is a complete revolution in the schema of the child, reflecting a total change in the concept. This is the desired conceptual change.

In their description, Driver et al. (1985), relate to some possible outcomes of combinations between new data and the existing schemas. But how does this specific piece of information enter the mind of the learner? Did this process affect the individual's learning ability? These questions remain unanswered in the Constructivist approach.

The theory of MLE provides a specific basis for the successful achievement of this process of conceptual change referred to above. Feuerstein et al.'s (1988) description of the learning process in a science museum, demonstrates the process that enables children to relate to scientific phenomena and scientific environments. The participants are the learners, the mediator and the scientific phenomena. The nature of the interactions of the two learners with the phenomena that are presented in the museum are compared.

The first learner who walks around without any mediation does not even look at the phenomena. She displays impulsive behaviour. This description suggests that learning does not necessarily occur even in the most attractively designed science museum. A learner can enjoy pressing buttons without even bothering to look at the phenomena.

The second learner received mediation from her mother that focused her observation on the relevant parts of the phenomenon and made the observation interesting with a prolonged dialogue before and after an

experiment that was performed in relation to the phenomenon. Observation of the details of the phenomenon was central to the learning process. It was the mother who gave the learner the cognitive prerequisite needed to observe the phenomenon, namely ‘conservation of constancies’. She led her daughter to observe the phenomenon before and after pressing the button, and to compare the two stages. The mother thus enabled her daughter to observe a physical environment and to identify the changes that took place. This careful observation enabled the girl to formulate the principle underlying the change that had occurred. She learnt that the change that took place was not random and that it was governed by scientific rules. She could now predict which changes would occur when she pushed the button or in other situations where a similar rule applied. Thus, the physical principle was conserved.

MLE involves active participation of the mediator and the learner in the learning process. It places emphasis on the observation process and on distancing oneself from the concrete phenomenon in order to be able to generalize. MLE involves the initiation of the learning process before the entry of the piece of information into the learner’s mind. MLE broadens the learner’s cognitive perspective, and provides the basis for a process of interaction between the learner and her environment.

The Instrumental Enrichment (IE) program

The Instrumental Enrichment (IE) program is the educational intervention or ‘thinking skills’ program designed by Feuerstein. It comprises 14 paper-and-pencil Instruments, each emphasizing different cognitive operations such as organization, comparison, inferential thinking, representational thinking, orientation in space and time, categorizations, etc.

Its guiding principles are of value in the design of other educational programs such as the EAC, presented here. The IE program does not relate to any specific content but affords the opportunity of applying its principles and strategies to different content areas. The goal of IE is to give the learner the necessary cognitive prerequisites for application in a wide variety of contexts. When the IE program is implemented in schools its aim is to equip students with strategies that they can apply flexibly in the process of learning different subjects. The IE program assists the individual to learn how to learn, thus empowering her and enabling her to benefit more from her studies. The presentation of a particular subject area in terms of IE principles involves the use of IE as a means to develop cognitive skills through the teaching of content.

The underlying approach of IE is to provide students with the skills for making the cognitive changes required to solve specific, increasingly complex and difficult problems. This enables students to succeed in

tasks that would otherwise be too difficult for them. The overall amount of content that they can learn is limited, which requires the construction of a new balance between content and process.

Mediated interaction in the classroom – The general objective of IE is to render the individual an independent or autonomous learner. Feuerstein's approach is to train her to become an independent learner through exposure to a sequence of tasks that are tackled with assistance from the mediator, who helps her to develop the strategies needed. The tasks reach a level of difficulty which obliges the learner initially to work together with the mediator, before gradually becoming more self-sufficient as the mediation becomes effective. Thus, at later stages the amount of mediation is diminished, as the learner internalizes the set of strategies and acquires experience regarding where and when to use them.

The Organization of Dots, which is the best-known of the IE Instruments, is briefly described here to illustrate the program. This Instrument deals with organization of dots according to a given model that must be formed from various configurations of dots in different forms on a page. The model and the configuration of dots change from one page to the other. The model is composed of a variety of geometrical figures, while the group of dots calls for organization according to certain principles. These principles can be applied to the organization of human and physical environments. For physics teaching, the group of dots may represent any type of physical environment or phenomenon. The model represents a physical principle or law that serves as our tool to organize the environment.

As the student's experience grows, she learns to use the diverse strategies for organization in different contexts and environments – she acquires flexibility of thinking. The student is active in solving the problems. In the process she changes her perception of the group of dots, from an initially blurred perception, to a learnt perception in which the fine details are observed. It may be interesting for the science teacher to note that by a systematic process the student attains a better observation of the phenomenon. She learns to observe some specific concentrations of dots or to see a separate dot detached from all the others. She also changes the way she observed the model. From a holistic view of the geometrical figures detached from any context, the student learns through her experience that she can relate to some special concentrations of dots within the model that will better help uncover the virtual shape hidden in the cloud of dots. This can teach her about the nature of the principle through its connections with the real environment. Systematic observation is a sound basis for projecting a form of organization onto a field.

The EAC – A *thinking journey* to the moon

Low functioning students and astronomy teaching

Myklebust (1983: p. 18) offers the following definition of low functioning students: ‘When children do not learn as expected in comparison with the average, although they are otherwise normal, they fall into the learning disability category’. This definition relates to the level of the performance of the students, which is a changeable entity that may be influenced by an outside intervention.

Working with low functioning students in the 9th grade means meeting with students who experienced difficulties at school during their eight previous years. The construction of an appropriate astronomy curriculum needed to address the specific difficulties of the students. Difficulties were observed in two main areas:

- (a) The use of the conventional language, that is, written language and especially mathematics;
 - (b) The ability to relate classroom and everyday knowledge to each other.
- In many cases, students were reluctant to apply the scientific knowledge to their experiences outside school.

A curriculum was thus developed that could relate to the difficulties of the students and which could afford them an interesting and motivating learning environment. A *Thinking Journey* was constructed through the use of astronomical pictures. Its basic idea was to enable the students to observe a given physical environment from new and different perspectives and to connect these with their everyday perspectives of the phenomena that they observe in this environment. The students are mediated through visits to, and observation of new places, as if they were tourists visiting faraway places with the assistance of a tour guide. Then the students return to their everyday environment and observe it in a new way.

A thinking journey

A *thinking journey* involves the design of a learning situation according to a combination of the MLE and the Constructivist approaches. It addresses very basic scientific concepts. However, it structures a broad encounter between the learner and the environment with provision for the intervention of a mediator. The basic encounter is not with scientific models or formulae but with the observation of phenomena. It is a simple task to observe a concrete environment, even if this is a remote land or the moon. What is important is not to stay at the level of constructing the story of the faraway place but to return to the everyday environment and to reconstruct its story. The use of cognitive functions enables one to

construct a *thinking journey* that relates to the cognitive processes that were used while going out on this journey and when returning to the environment. This can affect the cognitive functioning of the learner while dealing with physical environments. It can also affect her ability to relate to her everyday environment.

A *thinking journey* is based on observations of a physical environment from different perspectives. Each perspective enables the learner to construct a different 'story' (explanation) of the environment. The coordination between the different perspectives is the basis upon which the learner constructs her new concept of the phenomena that are seen in the environment, which means observing the environment in a new way.

The idea is to enable the learner to observe the place where she lives from a new perspective. People often go to great lengths in order to be able to observe themselves from a new perspective. The ability to distance oneself from the usual point of view of the near environment is a first step in the process of a conceptual change thereof. The process of conceptual change usually comprises a movement in the mind of the learner from the initial concept towards the scientific one. Vosniadou (1994) refers to the synthetic mental models that children construct in the process of combining the initial models of the concept of Earth with the scientific one. Vosniadou's approach concerns a two-way interaction in the learning process: the one involves the individual in learning about the characteristics of the scientific concept and adopting a more scientific point of view while the other is the influence exerted by the mediator on the way the learner observes her environment.

Understanding this interaction is important in the process of constructing teaching materials. As the initial concepts stem from the everyday perspective of observing the environment, the scientific model can be taught through observing pictures of the Earth from space. One can teach both aspects of this interaction through the emphasis on observation of phenomena: teaching the scientific concept through the process of observing scientific pictures and also relating at length to the way the learners observe the different environments in which they live.

In this way one can approach the vision of Driver et al. (1985) of changing all the learner's schemata by means of a scientific intervention. This can occur if the science lesson changes the way children observe their environments. This kind of influence can generalize to affect the learner outside the classroom too, which means that it will be used in many areas and for a longer period of time.

Using a pictorial modality

Since many students have difficulties with mathematical skills, ways must be found to enable them to interact with the physical environment,

while circumventing the mathematical obstacles. Using NASA pictures of the Earth, the moon and space, enables students to interact with a congenial modality. The term 'modality' is borrowed from Feuerstein's 'cognitive map', which is his description of the various cognitive dimensions of learning tasks. Feuerstein et al. (1991: p. 168) define modality as the *language of presentation* of a learning task.

Students find the pictorial modality familiar: they are accustomed to it in their everyday interaction with television, movies and computers. Perrig and Kintsch (1985) observe that the pictorial modality is easier for students to remember and to understand than the verbal modality.

The pictorial modality is the most common way of conveying astronomical data. The use of up-to-date NASA pictures enables the students to learn by observing these phenomena and building on their observations in the generalization process. They can wander around distant places in their minds, like tourists. They can also construct stories that these distant places tell. Even the most distant place can seem quite concrete to the students. This kind of modality enables the students to become acquainted with the nature of phenomena. The question that the students are asked is: What do you observe around you? They relate to data gathering and elaboration from observations, without the need to construct models, which can distract them from really observing the new environments.

Photographs from space constitute scientific information regularly used by astronomers, so that their use in an astronomy curriculum seems natural. The students are given the pictures and asked to analyse actual scientific information contained in them. The fact that this information is given in the congenial pictorial modality represents a sound reason for using unmodified photos from space as the basis for the curriculum's interactive mediated activities.

Contact with the physical environment involves relating to an abundance of stimuli. The pictorial learning tasks can provide learners with tools to find some organizing principles in the physical environment. The students learn that the environment can offer something new on every encounter. The ability to ask new questions and to observe the changes can enable students to predict what is going to happen in some phenomena in the environment.

The concept of Earth is unique in its established developmental sequence of notions and in the relationship between the initial and the scientific concepts. The fact that different researchers have found similar developmental sequences (Baxter, 1989; Nussbaum, 1971, 1985; Vosniadou, 1994; Vosniadou and Brewer, 1990) provides the teacher or the curriculum designer with a solid scientific foundation for determining the content of any curriculum intended to teach the concept of Earth.

The initial concept stems from the everyday perception of the environ-

ment that people living on the Earth have when they look around them. Any environment on Earth is only a small segment of the huge sphere, and thus seems flat to an observer standing on the ground.

The scientific concept relates to the Earth as a whole. For an observer from the moon, the Earth seems just like the description of the scientific concept: a spherical material body surrounded by a huge space; from this vantage point one can see the seas, clouds and the land on the outside part of the Earth, which can help in understanding that human beings live on the outside surface of the Earth.

The difference between the initial concept and the scientific one is in the point of view from which one observes the Earth. Both can be observed: the initial concept from a perspective on the ground and the scientific concept from a perspective near the moon. So if the learner is given the opportunity to observe the Earth from the moon, she can actually see the scientific concept. This gives a clue to the way one can design a conceptual change process in relation to the concept of Earth. The idea is to enable the learner to change her everyday point of view of the Earth. She will be able to understand that her everyday point of view has to include other perspectives of observing the Earth. This can enable her to observe it in a new way.

A *thinking journey* can lead the learner from the place where she observes the flat environment around her, to a place where she can observe through photographs the scientific concept of the Earth. So moving from the perception of the initial concept of the Earth to the perception of the scientific one can be done through the use of photographs showing different perspectives of the Earth. This may enable the student to extend her view of the Earth, and to show her that her initial perspective is just a particular case of the whole picture.

Strauss (1987) discusses the importance of the child's everyday knowledge in the process of formal teaching. In the teaching of the concept of Earth that involves the change of perspectives thereof, the initial perception of the Earth is not approached as something that has to be removed from the learner's mind and replaced by another concept, but rather as an important viewpoint which has its place even when the scientific concept is established. The integration of both perspectives can enable the learner to really observe her environment and understand it as a part of larger whole, the Earth. The learner has to be able to relate to the huge size of the Earth in order to understand that the two perspectives are complementary.

The initial perspective of the Earth will also be an important factor in the process of the change of perspective needed to observe the Earth from the moon. Only by projecting the relationship between the size of objects on the surface of the Earth and the size of the apparent moon, can the learner understand the new set of relationships as they are seen from the moon.

Comparison of the moon and the earth

Comparison (which is, as mentioned, one of the cognitive operations addressed by the IE program) is important in the process of knowing something. It is very difficult to understand something without being able to compare it to something else. Looking at ourselves in the mirror makes sense only if we compare the reflected face with other people that we know, to infer our age, height, the amount of gray hair, etc.

Our everyday perspective of the Earth is very misleading. There is no way to understand that we live on a planet, without comparing it to other celestial objects. The comparison process can enable the learner to conceive her near environment in a much wider context. It is a part of a planet, which is one of many celestial objects.

There is a need to apply to the outside view of the Earth an important cognitive operation: the *comparison* of the Earth to another celestial object. The natural choice for a comparison companion for the Earth is the moon, which is familiar to everyone on Earth and relates to our everyday view. The moon is similar to the Earth in its general external characteristics: it is a huge spherical body, surrounded by huge space with the down direction determined by gravity to the centre of it.

From the Earth, the moon appears as a small object located in the sky. Accordingly, seeing the moon up close and realizing that it is perceived as flat, and as a very large place that is similar to the Earth in its size, one can understand the relative conception of the Earth. From close by, it is seen as we are habituated to see it, while from a distance it resembles the way we see the moon: a sphere.

The problem with perception of the Earth is that it seems so familiar that it is often difficult to persuade students to examine it as a celestial body like any other. Many students have an egocentric view of the Earth, regarding it as a different entity than all the other celestial objects. Therefore it is not easy to convince them that the moon can be a source of comparison with the Earth.

The comparison process enables the student to move beyond the perspective that the Earth is a unique body in its own right and conceive of it in a broader context. This is a process of distancing from the concrete phenomenon and observing it as a part of a larger whole, the family of the planets. The comparison process enables the students to distance themselves from their egocentric view of the Earth and to get to understand the Earth better in the light of its comparison with other celestial entities. The comparison with the moon serves as the first step in a possible series of comparisons with other celestial objects that enables the students to widen their perspectives of observing the Earth.

In order to be able to compare the moon to the Earth, and to relate a moon's environment to an Earth one, the students are given a task, to

construct a story of being a whole Earth day on the moon. In that story the students relate to the physical phenomena that they encounter on the moon, but also place themselves on it and describe daily activities. They can describe writing letters to their friends on the Earth, where they can tell them about very special features of the moon's landscape and of the routine of their lives on the moon. They can relate themselves to children of astronauts, that were sent for a long stay on the moon. The students are required to describe specific phenomena on the moon and to relate to different environments on it. The construction of the story of the moon by the learner can lead her to observe many phenomena in a new way, and enable her to integrate these phenomena into a new reality. This experience of putting oneself on the moon for a period of time and telling its story, is the basis for rewriting the story of different environments on the Earth.

The mediation of cognitive functions to enable the student to change her perspective of the Earth as the first step in conceptual change

A process of teaching to bring about a conceptual change in chemistry, based on Feuerstein's MLE, was designed by Strang and Shayer (1993) and began with mediating the needed observations before moving on to the necessary generalizations. Strang and Shayer described a process that required the student to distance herself from a concrete chemical reaction in the process of learning the connections with the abstract description of a formula. The ability to change the level of abstraction lay in the mediation of the cognitive function of the conservation of constancies, that was taken from the list of deficient cognitive functions (see pp. 9–11).

The students had to be able to observe across the levels of abstraction and to understand the connection between a written letter and a substance that has a colour and a shape. In order to help them complete this journey across the levels of abstraction, Strang and Shayer introduced an interim level of symbols. These authors also attempted to develop the students' understanding of the concrete process of chemical reaction that took place in front of their eyes. They mediated (enhanced the understanding and applications of) the concept of conservation of weight in order for the students to realize that the same components were involved at the beginning and at the end of the chemical process.

Strang and Shayer's research demonstrated that the use of the cognitive function of *conservation of constancies* could aid in the mediation of better observations in the same dimension, but would also facilitate a journey to different levels of abstraction to permit comparison between environments that are observed in different dimensions. The mediation of the cognitive functions helped the students advance

within the same plane and also to change their viewpoint from one plane to another.

With regard to the concept of Earth, the mediation of the cognitive functions has similar objectives to Strang and Shayer's research. The students must be able to observe and understand different phenomena within the same environment and to relate to phenomena in environments within different dimensions. The students can learn by connecting the unknown to their existing knowledge base. Mediation of an unknown environment should take this into account, drawing on the different cognitive functions in order to lead the learning process and to enable the learner to connect between the known and the unknown.

The mediation for a conceptual change of the concept of Earth will use a combination of cognitive functions and one will have to understand the specific influence that the use of each cognitive function has on designing a relevant learning path. Thus, for example, mediation of *conservation of constancies* is central in the learner's ability to move from a known to an unknown environment. The learner has to see what properties stay unchanged when a change process takes place. In the process of teaching the concept of Earth, the students are shown photographs of both the Earth and the moon, once from the Earth's perspective and another time from the perspective of the moon. The requirement is for the students to be able to conceive of the Earth in both pictures as the same entity.

In order to understand students' difficulties in correlating different representations of the same objects, the following example may be useful. One is accustomed to seeing the moon during the night. When the students of the experimental class went out to observe the moon during day time, several students refused to accept that the object in the sky was the same moon they see at night. One said that it was just an unusually-shaped cloud, while another explained that it was not the real moon, but a reflection of it.

These comments led the teacher to realize that it is not enough to go out in day time and observe the moon, in order for the learners to accept its appearance at this unexpected time of the day. One has to relate specifically to two questions: What is the object seen in the sky? Is the moon that appears in the morning and at night the same object?

It is more difficult to understand the analogy between the two photographs, one of the moon seen from Earth and the other of Earth seen, in a phase, in a photograph taken by Apollo 11 from the moon. The mediation of the conservation of constancies determines one path that can be taken in the learning from the comparison of the two snapshots. If the Earth is the same Earth in the representation of both pictures, then one can learn that both perspectives relate to the same object, and one can regard the everyday perspective of the Earth that is shown in the picture from the Earth's perspective as complementary to the scientific

point of view of the Earth seen from the moon. The same process may be carried out vis-a-vis the moon in the two representations.

Another path of mediation can be used to understand the nature of observations of the same objects from different perspectives. Analogies are drawn from the everyday perception of the Earth when one observes the new environment on the moon. In order to understand that, from the perspective of a man standing on the moon, the flat environment is that of the moon and the Earth is seen in a phase, like the way the moon is seen from the Earth, one must compare the photograph with the perspective from the Earth, and appreciate the principle that the near environment will be seen as big and flat, while the distant environment will be seen as a sphere in a phase. This thinking process is called a *projection of relationships*. The relationships that are familiar to the learner in her everyday perspective are the organizing principles for understanding the perspective from the moon.

The coordination of perspectives is the cognitive process required to draw conclusions from the data gathered previously. In each picture there is a process of mediation of various cognitive functions, namely, *systematic data gathering, relating to the various sources of information* and increasing the *clarity of perception* of the aspects of pictures that were blurred to the learner. The different perspectives of the Earth and the moon are the building blocks that form a more comprehensive observation of these bodies. The coordination of perspectives is the prerequisite for understanding that the Earth and the moon have properties of planets. Thus, the process of distancing the learner from the concrete information and making more abstract generalizations carries on.

The mediation of different cognitive functions can lead learners to a variety of learning paths. The mediation based on each cognitive function leads to emphasize different cognitive elements and thus designing different cognitive processes. The use of a variety of these learning paths can enable students to undergo a comprehensive thinking process that can serve as a basis for conceptual changes and of differently relating to a variety of physical environments. The range of cognitive functions which is addressed and emphasized depends on the specific needs of the learners.

The active role of the teacher as a mediator

As mentioned earlier, the role of the teacher as mediator in relation to various learning activities is defined by Feuerstein et al. (1979; 1980; 1988; 1991) in terms of a number of criteria of MLE. Some of the most important of these are elaborated below, within the context of the Experimental Science Curriculum.

Schur et al.: MLE as a Vehicle for Teaching Science

Intentionality – The teacher leads the process through the mediation of thinking processes. She focuses the students' attention, sets the required pace and identifies the cognitive functions required to analyse the pictures and to generalize from a series of pictures. By activating cognitive processes, the teacher can guide the students without diminishing their level of activity.

Reciprocity – The teacher needs to be sensitive to the place of the students in the process. She has to be aware of the alternative concepts of the students and their relevant deficient cognitive functions. Usually students in different classes relate differently to the analysis of the pictures; the teacher constantly learns from the students' fresh approaches. The student's answers must be interpreted and their place in the developmental sequence of the concept of Earth understood. The mediation of reciprocity is the essential counterpart of the mediation of intentionality, since understanding the student and her abilities, needs and motives can enable the teacher to design the appropriate learning paths for her.

Transcendence – To design a *thinking journey* the teacher must maintain a balance between proximity and distance in relation to the relevant phenomena. This enables the students better to understand the concept of Earth through the process of widening their mental fields. They are shown the Earth according to various perspectives and as part of the nearby astronomic environment. This process, namely, a *thinking journey* which involves flexibly changing the perspectives of the Earth and its astronomic environment, can be used by the students when they are given individual projects that require them to investigate unknown astronomic objects or phenomena.

Meaning – The mediation of meaning involves the development of an understanding of the relevance of astronomy. Students are shown that it concerns their understanding of the place where they live, the Earth, and is based on their everyday perceptions. Gavish (1997: p. 37) observes that students assign a new meaning to learning after undergoing a learning process with a cognitive emphasis. Thus, the analysis and elaboration of pictorial astronomic information became a habit in the EAC classroom.

Sense of competence – In mediating the sense of competence, the feeling is communicated to students that they can succeed, by providing them with success experiences in small steps and thus, ultimately, affording success with the task as a whole. The curriculum is constructed as an incremental sequence of similar processes forming the large-scale process

of a *thinking journey*. Success in one lesson is an indication that long-term success is also possible. The teacher's mediation aims both to enable the student to succeed in tackling each problem solving situation and to be aware of her ability to master the task.

Challenge – The EAC presents a real challenge to most populations of students. Working with low functioning students does not mean giving them easy tasks. On the contrary, one can construct a challenge but provide the cognitive tools to enable the students to tackle it. The photographs of distant environments present a challenge for the students. They need to solve the problem of identifying the characteristics and the interrelationships among the objects of the unfamiliar environment. Though the use of a pictorial modality enables the students to relate to a congenial language of communication, the sheer fact that they have to visit faraway places represents a real challenge.

The mediation of the cognitive strategies needed to solve the problems is effected in a systematic way. The mediator makes the students aware of the strategies they had to use in order to organize the environment. The students can then use these later in similar situations.

'Creative repetitions' as the basis for constructing 'thinking journeys'

Feuerstein et al.'s (1991) idea of 'creative repetitions' is central to the construction of the curriculum. The idea is to construct learning activities in a way that will enable the learner to experience the same cognitive processes in different learning contexts. She is expected to be able to repeat these processes in a flexible way in new learning contexts. The curriculum is constructed from a series of mediated interactive classroom activities enabling the use of the mediation of the same cognitive processes in relating to the analysis of a variety of environments. The interaction in the classroom relates simultaneously to the lesson content and to the cognitive processes that are needed in order to relate to it. For example, data is gathered from the NASA photographs in a systematic way, using data gathering tables and students are made aware of the process they experienced. This cognitive process is repeated with the other pictures of the journey to the moon and then with the pictures of the journey to the space shuttle. Thus, the students can feel increasingly at ease with the process. They can concentrate on the new content and can develop cognitive skills for application to other contexts.

Aims of the study

The combination of Constructivist theory and the construct of MLE formed the basis for the design of an EAC. It was postulated that a

curriculum based on this particular combination of theoretical approaches would be effective in promoting a process of conceptual change in a wide range of students, including those who are academically low functioning. At the same time, an approach based on MLE and its enhancement of cognitive strategies, would afford a generalization of learning beyond a specific curriculum.

As astronomy is considered to be a difficult section of physics and one of its more up to date and interesting areas, it was chosen as the subject to be taught to a class of low functioning students. In particular, the EAC focused on enabling academically low functioning high school students to change their concepts of Earth via a process whereby appropriate cognitive strategies were mediated to them.

The general aim of this study was to evaluate the effectiveness of the EAC with this group of students. In particular, the study aimed to investigate the effectiveness of the EAC in (i) improving their level of understanding of the concept of Earth; (ii) improving the students' knowledge of astronomy; (iii) enhancing their general scientific knowledge, including non-astronomic scientific knowledge; (iv) enhancing their cognitive function/problem solving ability.

Method

Subjects

Selection of the sample – The experimental (E) group was composed of 14–15 year old students ($n = 16$) in two 9th grade classes of a religious high school for low functioning girls, which emphasized cognitive education. The goal of the school was to enable the students to pass the matriculation examinations. All students had received Feuerstein's IE program for two hours per week for 30 weeks in the previous academic year.

The reason for choosing this school was to evaluate the feasibility of teaching the EAC astronomy curriculum to students with a broad range of ability. As astronomy is usually taught in Israel to very high functioning students, it was thought that one should choose a sample of students that were not expected to succeed in learning astronomy. The school's reputation of students of low functioning religious girls seemed appropriate to the aims of the study.

In order to investigate the effectiveness of the intervention, the results of the E group were compared with that of a Control (C) group ($n = 16$), comprising students of similar learning achievements and the same age range and grade, who had also previously been given the IE program, and who now received instruction in the same topics as the E group, but

within the context of Geography (Earth Studies). The C group students came from the same school and studied the same lessons in the same classes. The only difference was that, while both groups received classes focused on the concept of Earth for three hours per week, the E group did so within the framework of the EAC while the C group was exposed to the conventional approach within the Earth Studies curriculum.

Measures

The measures were chosen to test the dependent variables of this study: knowledge of astronomy, general scientific knowledge, change in the notions of the concept of Earth and improvement in the cognitive skills of the students. The following tests were conducted:

International study of science education test – In 1983–1984 an international test of science education was conducted by the International Association for the Evaluation of Educational Achievement (IAEA) in 21 countries, including Israel and South Africa. The test comprised questions on physics, chemistry, biology, geology and astronomy. In Israel, the tests were translated into Hebrew and the research was conducted in 80 schools in the 5th, the 9th and 12th grades (Tamir et al., 1988).

The test was adapted to the needs of this study. Thirty four questions from the Hebrew translation of the test, including questions from all the fields of scientific knowledge, were selected from the test, ten of them from the domain of astronomy. The test was divided into two sections, each comprising 17 questions, including five astronomical questions. The reason for this division was a technical one: in the pilot study some school principles set a time limit for the implementation of the test, so one had the time only for one part of it. In the study itself, both sections were used.

Nussbaum's test – Nussbaum's (1971) Test is the classical method for determining the level of students in respect of the five notions of Earth. Nussbaum (1971: pp. 72–117) gives a detailed description of the test. Two versions of the test were used by Sharoni-Dagan (1979). These tests were designed to be given on the basis of personal interviews with the students.

Since this study aimed to test the students in a regular classroom situation with a restricted time limit, the Nussbaum test was edited: the three previous versions were used as the basis for preparing a new written version to be given as a written test to a whole class. This enabled a much larger number of students to be tested and required only one school hour (45 minutes) of class time.

Test of scientific thinking – TOUS (Test of Understanding Science) – A test prepared for testing the scientific thinking of junior-high school students was used in the pilot study. After using all five parts of the test during the first year of the pilot, only the last two parts were chosen, since the first three were too difficult for the students at the experimental school.

The first part of the test included questions concerning the movement of balls on inclined planes and required simultaneous consideration of two sources of information: the degree of inclination and the distance of the movement of the ball on the plane (and in one question, also the material of the ball).

The second part required consideration of given data relating to a hypothetical place where an unusual type of human race existed. The students were supposed to read the text carefully, to use hypothetical reasoning and to use syllogistic reasoning in one of the questions.

Procedure

Conducting the experiment – The EAC was implemented in Group E for three hours per week during the 30 weeks comprising the academic year. During that time Group C studied Earth studies. The Earth studies curriculum was taught by the regular experienced geography teacher, while EAC was taught by the school's biology teacher, since the school had no physics teacher and the EAC may be taught by science teachers from allied fields. The students in both groups were tested before and after the implementation of the EAC and the Earth studies curriculum, respectively.

Results

Effects of intervention on knowledge of astronomy

To determine the effects of the EAC on the E group, an Analysis of Covariance (ANCOVA) was conducted on the post-test scores (with the pre-test scores as covariates) of the E and C groups on the astronomy section of the International Study of Science Education Test (ISSET). Table 1 presents the means and standard deviations for each group and the results of the ANCOVA.

As Table 1 shows, the pre-test mean score of the C group on the test of astronomy knowledge remained virtually the same at the post-test, while the E group post-test score improved considerably as compared with its pre-test. The ANCOVA showed a significant difference between the E and C groups at $p < 0.001$. This significant improvement was in the knowledge of astronomy for the group undergoing the *Thinking Journey*.

Table 1 *Pre- and post-test results for E and C groups on the Astronomy questions of the ISSET*

	<i>E Group Mean</i>		<i>C Group Mean</i>		<i>F</i>
	<i>Pre-test</i>	<i>Post-test</i>	<i>Pre-test</i>	<i>Post-test</i>	
Science Test 1	38.75 (21.25)	72.5 (20.49)	35 (21.29)	37.5 (22.94)	19.72*
Science Test 2	47.5 (20.49)	76.25 (18.21)	48 (22.42)	50.6 (22.50)	14.05*

Note: Standard deviations are shown in parentheses below the mean scores.

* $p < 0.001$

Effects of intervention on general scientific knowledge

Table 2 presents the means, standard deviations and the results of the ANCOVA for the two groups on all the questions of the ISSET excluding the astronomy questions. This test was divided into two sections, the results for both of which are presented in Table 2.

As Table 2 shows, a significant post-test difference was yielded between the E and the C groups in general scientific knowledge in Section 1 at the $p < 0.01$ level. In Section 2 there were no significant differences in the post-test.

Table 2 *Pre- and post-test results for E and C groups on the general scientific knowledge questions of the ISSET*

<i>ISSET</i>	<i>E Group Mean</i>		<i>C Group Mean</i>		<i>F</i>
	<i>Pre-test</i>	<i>Post-test</i>	<i>Pre-test</i>	<i>Post-test</i>	
Section 1	55.88 (9.84)	70.95 (12.04)	52.44 (13.94)	57.71 (10.78)	9.10*
Section 2	57.72 (13.62)	75 (11.86)	58.82 (12.17)	69.01 (16.70)	2.15

Note: Standard deviations in brackets below the mean scores.

* $p < 0.01$

Change in the notions of the concept of earth

Notion 1 represents the initial concept of the Earth; Notions 2–4 represent what Vosniadou (1994) called ‘the synthetic concepts’, meaning that they combine the initial and the scientific concepts; *Notion 5* represents the scientific concept. As the numbers of the notions cannot be regarded as mathematical numbers, a non-parametric statistical method, the Wilcoxon Rank Sum Test, was used to assess the changes of the students in their concept of Earth. The results are presented in Table 3.

Table 3 Pre- and post-test results for the E and C groups in their notions of the concept of Earth, as measured by the Nussbaum Test

Group	Notion	
	Pre-test	Post-test
Experimental	1.72	3.69
Control	2.07	2.83
Z-Value	-0.91	-2.4*

* $p < 0.05$

As Table 3 shows, a significant difference was yielded between E and C in the degree of change they underwent in their notions of the concept of Earth. The E group started with a slightly weaker average notion than that of the C group. Both started quite close to the initial notion of the concept of Earth, though C started with a mean just above notion 2. However, by the end of the year, while C advanced to an average notion, between notions 2 and 3, the experimental group improved to a more accurate notion, approaching 4. Results on the Nussbaum Test indicate that, at the beginning of the year, most students of the E group were at the level of notion 1, which is the most basic and concrete notion. By the end of the year the average result of the E group students approached notion 4, which reflects an understanding that the Earth is a material sphere surrounded by a huge space and the down direction is generally pointed towards the surface (but not towards the centre) of the Earth. Getting the students to notion 4 was the target of the EAC. Indeed, at the beginning of the year only 12.5 percent of the E group students went beyond notion 4 whereas, after intervention, 43.7 percent of this group transcended notion 4 and 18.75 percent of them reached notion 5. By contrast, for the C group students there was no change at all, and the same proportion of 18.75 percent which held notion 4 or above at the beginning of the year, did so after their program of study too.

Change in cognitive skills

The direct target of the implementation of the EAC was to improve the students' knowledge of astronomy and to bring about a conceptual change in the concept of Earth. However, since the EAC was designed with an emphasis on mediating problem solving methods involving a diversity of cognitive strategies, there was some justification for expecting a transfer of the cognitive skills employed by the students in the EAC to other scientific problem solving situations.

In order to determine the extent of this cognitive transfer, the students were tested in two different problem solving situations that called for a variety of cognitive strategies. The first of these was constituted from problems on the Science Tests requiring the use of various cognitive

strategies. The second situation was constructed using the TOUS Test for Scientific Thinking, which assessed the use of cognitive skills in solving problems in new contexts. Results of E and C for each of these measures are presented in the following two sections respectively.

Change in solving cognitive-rich scientific problems – An analysis was made of the gains of the E and C group students in two selected questions of Science Test 1, namely Question 6 and 8, which were pertinent to the transfer of problem-solving abilities.

Question 6 required the determination of the sequence of extinguishing candles that were situated in different boxes. The question involves the use of sequencing in space (different boxes) and time (relating to the time of extinction) and requires the avoidance of answers that give a sequential order of 1–2–3 or 3–2–1, which some students see as the most plausible order of any sequence. Instead the question requires the simultaneous consideration of various sources of information.

Question 8 requires the analysis of a table of data relating to the percentage of fat in the milk of different mammals, and the effect of this difference in terms of the time required for the new-born animal to double its weight. This question involves application of the principle of inverse proportion, and again requires the simultaneous consideration of several sources of information.

The results of the students on these questions are presented in Table 4.

Table 4 *Number and percentage of students in E and C groups giving correct answers to Cognitively Rich scientific problems before and after intervention*

Question Number	E Group					C Group				
	Pre-test		Post-test		Gain	Pre-test		Post-test		Gain
	N	%	N	%	N	N	&	N	%	N
6	9	56	15	94	6	9	56	10	62	1
8	5	31	10	62	5	4	25	4	25	0

As Table 4 shows, E improved considerably more than C on both questions. In Question 6 both groups started with nine students obtaining the correct solution. The E group on the post-test had 15 correct solutions, while the C group had only ten. Similarly, on Question 8, the C started and ended with only four having the correct solution, whereas E started with five and ended with ten.

Changes on the scientific thinking test (TOUS) – To determine whether their ability to think scientifically and their problem solving ability had improved, the students of groups E and C were examined at the beginning and at the end of the year on the TOUS Scientific Thinking Test. The results are presented in Table 5.

Table 5 Pre- and post-test results for the E and C groups on the TOUS Scientific Thinking Test

	<i>E Group</i>		<i>C Group</i>		<i>ANCOVA (F)</i>	
	<i>Mean Scores</i>		<i>Mean Scores</i>			
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Physical Thinking	52.53 (19.52)	58.50 (13.90)	45.06 (20.75)	46.80 (14.77)	3.30	6.12*

Note: Standard deviations in brackets below the mean scores

* $p < 0.05$

As Table 5 shows, following intervention a significant difference was yielded between the E and the C groups on the TOUS Scientific Thinking Test, suggesting that the EAC enhanced the ability of the students to think scientifically.

Discussion

The results demonstrated that the EAC, derived from a combination of constructivist theory and the construct of MLE, was effective with a group of low functioning students. The EAC was more effective than an Earth Studies program in promoting a process of change in the conceptualization of Earth, notwithstanding the fact that the explicit aim of the latter program was to teach the concept of Earth. Earth Studies had been implemented for years at the school included in the study, and was taught by a skilful and experienced teacher.

Moreover, the EAC was also successful in improving the students' knowledge of astronomy, enhancing their general scientific knowledge and developing their cognitive functioning and problem solving ability.

The belief in the cognitive modifiability of human beings underlies the theory and practice of Feuerstein. However, he and his associates (for example Feuerstein et al., 1991) advocate and have provided 'content free' contexts, such as the IE program, for systematic training in the use of cognitive functions. Intensive and focused training, not attached to any particular subject matter and using a range of materials, is aimed at developing the students' thinking skills by providing them with the cognitive skills and operations for improved functioning across content areas.

The approach espoused in this study was a different one. It involved the development and application of cognitive functions through the mediation of a particular subject, namely astronomy. Thus, in contrast to IE, the aim of the EAC was to promote the acquisition of general cognitive functions by providing the specific cognitive prerequisites for conceptual change in a particular subject area. The EAC required students to relate simultaneously to the content and to the necessary cognitive processes. While the students improved their astronomical knowledge, they also became better learners of space photographs. As the process repeated itself creatively, it enabled the students to give increasing attention to the content, as they became more efficient in their specific cognitive functioning. This dual goal was implemented in the mediated interactions from which the curriculum was constructed.

Some of the difficulties encountered by the students in undergoing the process of conceptual change relate not to the nature of the scientific concept, but rather to their difficulties in gathering and/or elaborating the relevant information. The mediation of the relevant cognitive processes responds to the need to develop a plan-of-action that addresses the expected difficulties of the students with the process.

The goal of the curriculum was not to enable the students to pass difficult examinations, but rather to make astronomy an interesting and motivating subject. This allowed the construction of the EAC in a modality that would be as 'student friendly' as possible; namely a pictorial modality. This modality was very appealing to the students. Among other considerations, the astronomy photographs were chosen for their aesthetic beauty. Further, the students did not require previous knowledge to relate to the content. At the same time, the photographs formed part of an important scientific area. Indeed, the fact that the photographs made the students knowledgeable about up-to-date astronomical data helped raise their self-esteem.

The photographs were useful in enabling the students to construct a total representation of the relevant environments. They could relate simultaneously to complex phenomena and they were able to construct an image of these phenomena. Further, the process of mediated interactions enabled the students to form connections between different pictures, and to make a 'thinking journey' out of their connection. This process enabled the students to construct a 'story' of the phenomenon, as if they were travellers visiting it. The most important part of the process was to relate back to the students' everyday environment and to use the experiences from the far away places as a means to reconstruct the 'story' of their everyday environment.

The students in the Experimental group improved their scientific problem solving ability, suggesting the usefulness of utilizing a scientific

subject as part of an educational intervention designed to enhance the cognitive abilities of low functioning students. Adolescents and adults can benefit from an intervention based on a contemporary scientific topic like that embodied by the EAC. Science teaching can thus be conceived as a basis for enabling students to observe their environment in a new way.

The construction of a curriculum for teaching a complicated subject to low functioning students should take into account the need to work with them explicitly on their cognitive functioning. This demands a dual focus on both the content and the cognitive processes. Such a curriculum must concentrate on the core of the required content and provide sufficient time and 'creative repetitions' for students to master it.

In the EAC, the astronomy curriculum dealt exclusively with the relatively limited subject of the Earth-moon system, and only to the concept of the static Earth. The curriculum was conveyed through a series of mediated interactions, each of which required concurrent work on conceptual and cognitive processes. This approach enabled the students to change their concepts of Earth and to become better problem solvers while learning to observe their everyday environment in a new way through a thinking journey in the field of astronomy.

The principles of a *thinking journey* can be used in other content areas too. This was done by the first author in several school classes in both scientific and non-scientific subjects. Further, the combination of Constructivism and MLE can produce domain-specific curricula, and more general ideas for using science teaching as a means of enhancing students' cognitive skills. The use of *thinking journeys* in various contexts and subject domains is a subject for further research.

Finally, since all students in both the Experimental and Control groups had previously been exposed to an IE ('content free') program, involving the development of cognitive skills, it would appear that the EAC itself was the significant variable in producing the changes yielded for the Experimental group here. However, a further study is needed which compares the relative effectiveness of IE-plus-EAC in relation to EAC-without-IE, in order to assess the value of the IE as a basis on which the EAC could build. For it might have been the cumulative effect of providing general thinking skills using IE, followed by a consolidation of the skills within a particular subject area, that produced the significant changes.

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