Computers & Education 95 (2016) 296–308

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

Improving children's cognitive modifiability by dynamic assessment in 3D Immersive Virtual Reality environments

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ARTICLE INFO

Article history:
Received 24 February 2015
Received in revised form 23 January 2016
Accepted 25 January 2016
Available online 28 January 2016

Keywords:
Dynamic assessment
Mediated learning strategies
Cognitive modifiability
Analogical reasoning
Virtual reality

ABSTRACT

Increasing evidence reveals the efficacy of dynamic assessment (DA) procedure in providing rich and reliable feedback regarding children's cognitive modifiability. The DA procedure included four phases: pre-teaching test, teaching, post-teaching and transfer test two weeks after teaching. The teaching phase includes mediated learning experience strategies. Children's cognitive modifiability was examined by pre- to post-teaching improvement and by the transfer test. Children in Grades 1 and 2 ($n = 117$) were randomly assigned into three experimental groups and one control group. Each of the experimental groups was given the teaching phase in a different modality: 3D Immersive Virtual Reality (IVR, $n = 36$), 2D ($n = 36$), and tangible blocks (TB, $n = 24$). The control group ($n = 21$) was not given teaching phase. The teaching phase included strategies of solving problems from the *Analogies* Subtest of the *Cognitive Modifiability Battery* (CMB). Pre- and post-teaching CMB Analogies tests were administered to all groups followed by CMB Transfer Analogies two weeks later. The findings indicate that the 2D and TB groups showed higher cognitive modifiability than the control group. Also, the findings indicate that teaching in a 3D IVR environment contributed to the children's cognitive modifiability more than in the other groups in the CMB Transfer Analogies. The findings are discussed in relation to the unique enhancing characteristics of the 3D IVR condition combined with the applied mediation strategies.

1. Introduction

The main objective of this research was to study the degree to which learning process in a dynamic assessment (DA) procedure using a computerized 3D Immersive Virtual Reality (3D IVR) framework contributes to cognitive modifiability of children as compared to DA in computerized 2D and in non-computerized environment using tangible blocks (TB). The effects of learning in these three situations on children's cognitive modifiability were examined using analogical problem-solving from the *Cognitive Modifiability Battery* (Tzuriel, 1995, 2000).

DA refers to assessment – via a process of active teaching – of an individual's perception, learning, thinking, and problem-solving. This process is aimed at modifying an individual's cognitive functioning and observing subsequent changes in learning and problem-solving patterns *within* the testing situation (Tzuriel, 2001). Unlike standardized assessment, where examiners seek to document an individual's existing repertoire of cognitive abilities and make no attempt to change, guide, or

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http://dx.doi.org/10.1016/j.compedu.2016.01.009
0360-1315/

improve the individual's performance, the main goal of DA is to assess changes in performance *within the test situation*. The changes are taken as indications of cognitive modifiability, that is, future development that will be realized provided that a cognitive intervention is applied later.

A central construct in the DA approach is *cognitive modifiability*. This may be defined as the individual's propensity to learn from new experiences and learning opportunities and to change one's own cognitive structures in similar or more advanced learning situations (Feuerstein, Feuerstein, Falik, & Rand, 2002; Feuerstein, Rand, Hoffman, & Miler, 1980; Tzuriel, 2001, 2011, 2013). The mediation (teaching) strategies used within the DA procedure are based primarily on *mediated learning experience* (MLE) theory (Feuerstein et al. 2002; Tzuriel, 2001). It should be emphasized that in the current study we limited ourselves only to the effects of the short-term teaching phase of the DA procedure on cognitive modifiability as indicated by (a) pre- to post teaching improvement and (b) performance on analogy transfer problems. Before turning to the specifics of this study, we discuss the MLE theory, the DA approach, DA in computerized environments, analogical reasoning, and finally DA studies using analogical reasoning operation.

1.1. MLE theory

Mediated learning experience (MLE) is an interactional process in which parents, teachers, examiners, or peers, interpose themselves between a set of stimuli and the learner, and modify the stimuli for the developing child (Feuerstein, et al., 1980, 2002). Feuerstein et al., (2002) suggested 12 criteria of MLE, however, only the first five were used operationally in educational and developmental research (Shamir & Tzuriel, 2004; Tzuriel, 2011, 2013; Tzuriel & Shamir, 2007, 2010a,b). These five MLE criteria are: *Intentionality and Reciprocity* (e.g., focusing, alerting and changing focus based on reciprocity of learner), *Meaning* (e.g., provision of affect and importance), *Transcendence* (e.g., expanding information by teaching principles and rules beyond the concrete information), *Feelings of Competence* (e.g., rewarding, interpreting successful performance, preparing conditions for success), and *Self-Regulation* (e.g., monitoring impulsive behavior, sequencing order of activity). An interaction can be defined as mediated interaction if it contains the first three criteria or “ingredients” of mediation. These criteria are considered as necessary for an interaction to be classified as MLE. The last two criteria are optional but their existence strengthens the mediation process (For a more detailed description of the MLE theory readers are directed to Feuerstein et al., 2002).

According to Feuerstein, the MLE strategies help children internalize learning mechanisms, facilitate learning processes and self-mediation, give indications about future changes of cognitive structures, develop deficient cognitive functions, and provide for the ability to benefit in the future from mediation in other contexts. For example, a child who receives adequate mediation for Transcendence (e.g., expanding, teaching principles and rules) internalizes this specific type of mediation and will use it efficiently in other contexts. The efficient use is not limited only to provision of mediation by others but also to generation of transcendence when confronted with new situations. The child will transfer the rules and strategies learned previously to other problems that vary in terms of content domain, and levels of complexity, novelty, and abstraction. In the same way, children who experience an adequate amount of mediation for Meaning (e.g., experiencing the worth and significance of an object or event) internalize this interaction and will use it later in various contexts. They will not be only more open to mediation for meaning from others but also will initiate attachment of meaning to new information rather than passively waiting for meaning to come.

According to the MLE theory, intelligence is defined by the individual's ability to change itself, and to use the principles and behavior models it studied in the past for the sake of adapting to new conditions. Based on this theory, it is impossible to estimate cognitive modifiability on the basis of previous learning experiences, or on the basis of the final product of those learning experiences (achievements). The emphasis must be placed on the learning process and on the assessment of the individual's ability to modify cognitive functions.

In our research we examined the child's cognitive modifiability by means of dynamic assessment using MLE strategies in computerized environments.

In the following we describe the DA approach and its relation to cognitive modifiability as measured in the current study.

1.2. Dynamic assessment (DA) approach

The DA procedure represents a relatively new trend in evaluating the individual's learning potential. It is suggested as a replacement to the widespread system of static assessment in evaluating a child's cognitive modifiability. DA focuses on examining and measuring the child's ability to modify cognition, with the assistance of within-test teaching. The idea in this procedure is to observe the changes that the individual goes through as an indicator of the cognitive modifiability hidden within her/him. With the conventional static procedure, the only thing measured is the manifested level of the individual's achievements, without any attempts at intervention in order to observe cognitive modifiability (Tzuriel, 2001).

Tzuriel (2001) broadened the DA approach to include applicability to early childhood and defined its special characteristics. These include diagnostic materials, processes of mediation adapted to the developmental stage of concrete operations, evaluation techniques and various DA instruments for early childhood (Tzuriel, 2001, 2011, 2013). The DA procedures developed are integrative taking into account task characteristics (e.g., type of cognitive operation), dimensions of the learner (e.g., intrinsic motivation, accessibility to mediation), and of the mediation processes (e.g., specific mediation strategies). The task's dimensions are based on contents appropriate to early childhood. They include colored stimuli and tangible materials with game-like characteristics. The focus of assessment is on cognitive changes, mediation strategies and learning processes. The levels of complexity and abstraction of the tasks run from simple to complex and from concrete to abstract. The characteristics of the child being assessed generally refer to the evaluations of his/her thinking, motivational, emotional, and personality dimensions, which influence the child at the time when s/he is being evaluated, taking into consideration the developmental phase s/he has reached. According to Tzuriel (2001), the examiner should be attentive to the child's needs, adjust his/her mediation to the child's cognitive level and adapt his/her tone of voice and body language to those of the condition of the child.

The present study was carried out according to the measurement/research version (Tzuriel, 2001). According to this procedure there are three stages: pre-teaching, teaching, and post-teaching. Before testing there is a preliminary stage designed to acquaint the child with the dimensions of the test and with problem-solving strategies. The pre- and post-teaching phases contain parallel problems thus allowing evaluation of improvement of performance. In the teaching phase, the child receives mediation for strategies of problem solving. The child's performance is measured quantitatively and the improvement from pre- to post-teaching phases indicates the level of cognitive modifiability. The CMB Analogies (Tzuriel, 1995, 2000) used in the current study include test and transfer stages (See Method). The transfer stage is based on the same dimensions and problem-solving strategies that had been learned during the test stage but with more complex problems than the original test problems. Transfer is considered in the literature as an indicator for internalization of learned principles, relationships, and strategies (e.g., Bransford, Brown, & Cocking, 2004; Cox, 1997; Perkins & Salomon, 1992; Salomon & Perkins, 1989) and is considered to be central in evaluating internalization processes (Kaniel, 2001).

The transfer problems of the CMB Analogies used in the current study represent what Salomon and Perkins (1989) named “high-road” transfer. The transfer analogies represent a leap in level of abstraction and complexity from the problems presented in the test phase (Tzuriel, 2000). Success in solving transfer problems highlights the degree to which the individual has internalized the principles of solving the original problems, and serves as an important indicator of cognitive modifiability (Tzuriel, 2001).

1.3. *DA in computerized environments*

One of the goals of the current study was to examine the impact of 3D Immersive Virtual Reality (3D IVR) on cognitive modifiability of children while learning during a DA procedure with tools that were found to be efficient in early childhood ages. Over the years, a few studies were conducted with a DA procedure to establish the validity and efficacy of the CMB as predictive tool of learning ability in Israel (i.e., Tzuriel, 2000) and the UK (i.e. Lauchlan & Elliott, 2001) (see method section).

Many studies have indicated that computerized environments contribute to the development of cognitive abilities among children (e.g., Clements & Samara, 2002), and that practicing cognitive abilities in a 3D IVR improve significantly cognitive achievements (e.g., Eden & Passig, 2007; Passig & Eden, 2000, 2002; Passig & Miler, 2014). Experience with a virtual reality environment is characterized by sensations of immersion and presence which enable the subject to feel as if s/he is part of the environment in which s/he is functioning. In a virtual environment it is also possible to present abstract concepts and novel points of view which cannot be presented in this way in the real world. We assumed that these characteristics would fit the DA procedure and the early childhood cognitive measurement tools and that they could serve as empowering platforms in the teaching and assessment processes.

Thus, in our research we examined the child's cognitive modifiability by means of DA using MLE strategies in 3D IVR as compared with 2D computerized environment and tangible blocks condition. We believe that by combining a DA approach with 3D IVR we are enabling the child's problem solving skills, in general, and analogical reasoning skills in particular.

1.4. *Analogical reasoning*

Analogical reasoning was chosen as the main cognitive operation of thinking because its centrality to the cognitive development of children (Halford, 1993; Holyoak, 2004; Richland, Morrison, & Holyoak, 2006). In a number of studies it was found that even children at the age of 3 and 4 years old demonstrate an ability to solve analogical problems, though they fail to reach a high level of ability until they have entered maturity (e.g., Richland et al., 2006).

Although the general consensus is that analogical capability is important to a child's cognitive development, there is lack of agreement regarding the mechanism involved in developing analogical reasoning. Over the years, a number of theories have been offered to explain the development of analogical reasoning (e.g., Csapó, 1997; Gentner & Markman, 1997; Goswami, 1989, 1991, 1992; Halford, 1993; Holyoak & Thagard, 1995, 1997; Klauer & Phye, 2008; Piaget & Inhelder, 1969; Siegler & Svetina, 2002; Sternberg, 1977).

According to Piaget, the ability to reach conclusions about relationships begins to develop at approximately the age of seven years. At that age, children begin to solve problems whose solution demands the sorting of things, ideas, or people into groups. The ability to sort into groups indicates an ability to understand the connections between objects or entities in a group, which consequently leads to the development of new relations between these objects, *i.e.*, dealing with higher order relational reasoning and understanding the principle of identity between relationships. Understanding the identity between the relations enables the connection between terms A to B with respect to the connector of the terms C to D. The ability of processing an analogy from a higher order of relational reasoning takes place in the formal operations stage, around the ages 11 to 12. At a younger age, children think linearly about relations in analogies, in the way that they choose one relationship in order to make a connection between terms A to B of the analogy, and another relationship in order to make the connection between the terms C and D. This type of reasoning is called lower order relational reasoning.

Two derivative theories have developed as competitive offshoots of Piaget's theory: The *Relational Primary Theory* (Goswami, 1991) and *the Relational Shift Theory* (Gentner, 1996). According to Goswami, solving analogies is difficult because of the difficulty in understanding the relationships between terms, and not necessarily because of the difficulty in coping with the process of reasoning and reaching conclusions. Goswami's assumption is that analogical reasoning starts from a young age and continues to develop as long as the personal store of knowledge of relevant relationships at our disposal continues to widen. The transition to understanding relationships depends on the child's level of knowledge and not on his/her age. Gentner (1996) suggested that a child's ability to think analogically becomes possible when s/he experiences a change called transition in relationships. At first, the child explains the analogy in terms of the similarity between objects and/or traits. In solving problems by using analogical reasoning, this aspect expresses itself by producing a relatively high frequency of errors, whose similarity is a likeness between objects. This aspect becomes progressively smaller as the child grows older, and gradually moves to reason on the basis of relationships.

Moreover, in the literature one can find that inhibitory control and additional working memory of executive functions have been posited to explain analogical reasoning capacity in children (Richland et al., 2006; Thibaut, French, & Vezneva, 2010) and adults (Krawczyk et al., 2008). The studies indicate that both inhibitory control and composite executive-function skills, such as goal shifting, and manipulating information held in a mental set, make independent, specialized contributions to children's analytical-reasoning development (Richland & Burchinal, 2013). The studies also suggest that the development of analogical reasoning depends on the interplay among relational knowledge, the capacity to integrate multiple relations, and the inhibitory control over featural distraction (Richland et al., 2006).

1.5. DA using analogical reasoning

An interesting result found in DA research using analogical reasoning modality was that young children at 5–6 years old age succeed in solving analogical problems on a much higher level after a short intensive phase of teaching than what one would expect from children of that age (Tzuriel, 2000, 2001, 2007). Several researchers found that mediation in analogical reasoning relevant to children and based on familiar relationships and concrete imaging, helped young children solve analogies (Richland et al., 2006). Another finding was that when children had prior learning experience with analogical reasoning, they used it more frequently and spontaneously in solving other analogical problems even weeks later, as compared with control group that had no prior learning experience and only practiced solving analogical problems, and control group that had no prior learning experience and no prior practice experience (Tunteler & Resing, 2007). In other words, studies have found that a methodical process of learning how to solve analogical problems can be preserved over a relatively long period of time.

In several DA studies researchers differentiated between perceptual analogies and conceptual analogies (i.e., Goswami, 1991; Tzuriel, 2007; Tzuriel & Galinka, 2000). Conceptual analogies express the semantic relations between familiar objects, so that prior knowledge is needed to solve those problems, while perceptual analogies express visual relationships between familiar things such as color, size, location, and quantity. In perceptual analogies the relevant information can be found in the problem itself, and there is no need to call it up from memory. Conceptual analogies, on the other hand, are based on a higher level of components' processing. They are more abstract, and their solution demands a higher level of concepts and relationships. While both kinds of analogies require the identification and mapping of the perceptual hints embedded in the analogies, the conceptual analogies demand, beyond that, an abstraction of the relations between the terms A and B and their application to the terms C and D of the analogy.

In the present study, we conducted a DA teaching process on perceptual analogies and their solutions in a computerized 3D IVR environment and in 2D environment. The presentation of tasks by the computer and the mediation process was equivalent in both groups. We measured the individual's cognitive modifiability according to her/his ability to use principles s/he had learned for solving problems which became more complicated than the problems s/he was trained in (i.e., transfer problems). The assumption of this study was that the experience of learning in a DA procedure in different computerized environments (3D, 2D) would better reflect the child's potential for analogical reasoning than in a tangible blocks situation. In addition, we assumed that 3D IVR is a platform which is suitable for assessing cognitive ability, and that learning in 3D IVR is effective in adopting strategies for solving analogical problems which had been mediated.

Essentially, we sought to examine whether DA within 3D IVR could enable children better express their cognitive abilities and enhance their cognitive modifiability. Our hypotheses were that cognitive modifiability would be the highest in children participating in a 3D IVR condition followed in that order by 2D computerized environment, tangible blocks non-computerized environment, and the control condition, and that all experimental groups will show higher improvement than the control group.

Table 1
Number of boys and girls in the sample.

Group	Boys		Girls	
	N	%	N	%
1. 3D IVR	19	52.6	17	47.4
2. 2D	21	58.3	15	41.7
3. Tangible Blocks	12	50.0	12	50.0
4. Control	9	42.9	12	57.1
Total	61	52.1	56	47.9

2. Method

2.1. Participants

A group of 117 children (61 boys and 56 girls) were randomly drawn from first and second grades from two elementary schools located in a two middle-sized cities in central Israel to participate in this study. Hebrew was the primary language in their home. The children's age range was between 72 and 102 months (M = 90.00, SD = 6.88). Children diagnosed as having learning difficulties were not included in the research. All the other children were assigned randomly into four groups of the study. It should be noted that five parents from the control group and four parents from the tangible blocks group withdrew their consent after group assignment (probably because their children were not randomly assigned to a technologically attractive group), hence the relatively smaller number of children in these groups. In recruiting the participants we asked first for parental consent. Out of 167 parents 127 gave their consent. Ten children dropped out of the study at the beginning of the DA procedure, because of lack of interest, despite their parents' consent. The number of boys and girls in each of the study's subgroups is presented in Table 1.

Gender composition in each subgroup did not reveal significant differences $\chi^2 = 0.75$, df = 1, *ns*. The age of children and parents years of education in the four groups is presented in Table 2. Significant group differences were found only in father's years of education.

Scheffe's analysis revealed significant difference between the Tangible Blocks and the 3D-IVR groups only in fathers' years of education.

2.2. Measures

2.2.1. Analogies Subtest from the Cognitive Modifiability Battery (CMB)

For this study we developed two computerized versions of the CMB Analogies: a 2D computerized mode (using a mouse and screen interface) and a 3D computerized mode (3D IVR interface). The goal of this test was to assess young children's cognitive modifiability in the analogical reasoning domain. The CMB Analogies was designed for children in the age range of kindergarten to fourth grade, but also suitable for children with learning difficulties in the fifth through eighth grades. The diagnostic procedure is based on the mediated learning experience theory (Feuerstein et al., 1980, 2002).

The Analogies subtest includes a preliminary-baseline stage aimed at preparing the child for testing. The preparation is done by acquainting the child with the test dimensions and with the basic rules for solving problems. The test is constructed of a wooden board (18 cm × 18 cm) which includes 9 windows set in a 3 × 3 format, and 64 wooden blocks in four colors (yellow, blue, red and green). For each color there are blocks in four heights (2 cm, 3 cm, 4 cm and 5 cm). The examiner places the blocks in three open windows (top-left, top-right, bottom-left) and the child has to complete the last open window (bottom-right) (see Fig. 1). The child is encouraged to solve the problems both horizontally and vertically. The problems are presented to the examiner in a booklet of problems.

The CMB Analogies subtest includes two sections: Test problems (14 items) and transfer problems (9 items). In both, the problems include three parallel items for pre-teaching, teaching, and post-teaching. The goal of the transfer problems is to assess the degree of internalization of the analogy principles taught in the test section. All problems in the CMB Analogies subtest are based on dimensions of color, height, number and location (See Figs. 1 and 2). The Test problems are constructed

Table 2
Parent's age and years of education in the four groups of the study.

		3D-IVR	2D	Tangible Blocks	Control	F(3,113)	Eta^2
Age	M	92.30	88.89	88.66	88.23	2.59	06.
	SD	6.08	7.21	6.12	6.79	–	–
Father's years of education	M	16.94	16.91	14.91	15.42	*3.26	08.
	SD	3.38	2.81	3.06	2.83	–	–
Mother's years of education	M	16.56	16.19	15.42	16.19	1.09	03.
	SD	2.26	2.57	2.65	1.99	–	–

*$p < 0.05$.

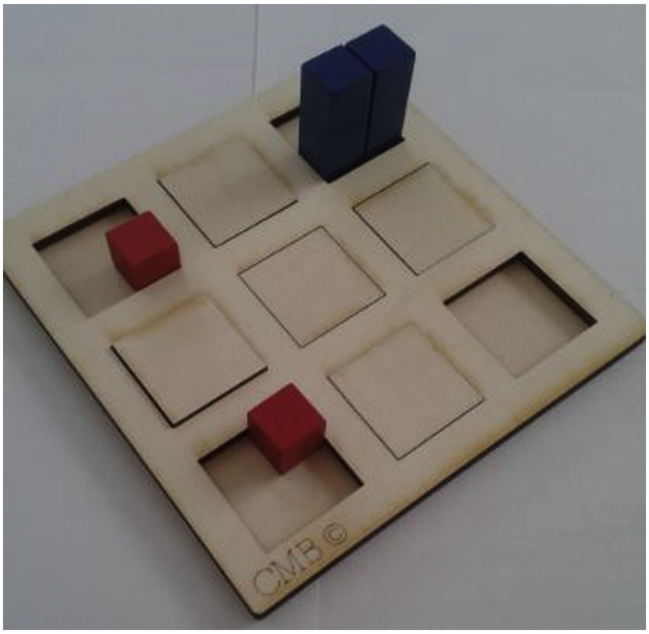

Fig. 1. Example of analogy problem from the CMB-Analogies Subtest (AN14-A).

from three levels of difficulty, derived from the number of dimensions included in the problem and arranged from easy to difficult. The dimension of location is considered to be the most difficult of all.

The transfer problems are based on the same dimensions and analogy principles taught in the test section but more complex in terms of the number of dimensions (color, height, number, and location) and the degree of abstraction required. In the present study we administered the Transfer problems according to the static approach.

An example of a transfer problem (TR8-A) is demonstrated in Fig. 2. The test section is carried out with pre-teaching, teaching and post-teaching stages, thus, enabling assessment of the child's cognitive modifiability. In the original

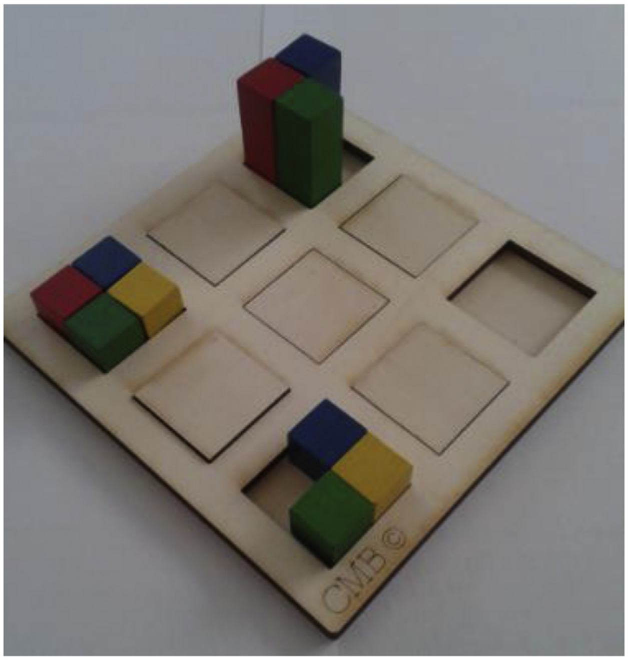

Fig. 2. Example of a transfer problem from the CMB Analogies Subtest (TR8-A).

administration each problem is laid out on the board in three open windows and the child has to complete the last open window by choosing the correct blocks from a pile of blocks (see Figs. 1 and 2). In the pre- and post-teaching phases no mediation is provided, except for giving instructions, as needed, or light probing (e.g., "look in both directions", "don't rush", "check your answer one more time"). In the teaching phase the child is taught to look for the relevant dimensions of the problem, develop a systematic exploratory behavior, acquire need for accuracy, understand the transformation rules of analogy, and improve performance efficiency. The mediation strategies include also non-verbal focusing, labeling, verbal anticipation of correct answer, and "rhythmic intonation" of contents.

Two main approaches may be used in teaching analogies: analytic and transformative. According to the analytic approach, each dimension is analyzed separately followed by integration of all dimensions. The examiner might sometimes use animation ("the big red block here is a friend of the big yellow block"). According to the transformative approach, the examiner teaches the child the rules of transforming relations between blocks ("on the top side the red block changes from red to green, but the height, number and location remain the same, so also in the bottom side the red block should change from red to green and the rest of the dimensions remain the same"). In the current study, we used both approaches interchangeably. Scoring was carried out only for the pre- and post-teaching phases and the improvement. The pre- and post-teaching scores served for the analysis of the child's cognitive modifiability.

The scoring method was all or none (Tzuriel, 2000). In this method, a score of 1 is given for each correctly solved dimension. The total number of scores was 14 for the pre-teaching and 14 for the post-teaching tests. Cronbach's alpha reliability coefficient of the original tangible format is 0.83 and 0.78 for pre- and post-teaching stages, respectively (Tzuriel, 2000). The CMB has been validated in several studies in the UK (e.g., Lauchlan & Elliott, 2001) and in Israel (Isman & Tzuriel, 2015; Tzuriel, 2000; Tzuriel & Caspi, 2015; Tzuriel & George, 2009; Tzuriel & Shamir, 2007, 2010a,b). For example, in Tzuriel (2000) study on a sample of Grade 1 children ($n = 35$) reading comprehension was predicted by the CMB post-teaching Seriation and post-teaching Analogies scores ($R^2 = 0.45$). The prediction of reading comprehension by the Analogies post-teaching score was more powerful ($\beta = 0.60$) than by the Seriation post-teaching score ($\beta = 0.27$). This finding was explained by the fact that Analogies taps an abstraction domain, which is closer to reading comprehension than Seriation. Further validation of the CMB Analogies subtest was reported by in a study aimed investigating the effectiveness of the PMYC program (Tzuriel & Caspi, 2015; Tzuriel & Shamir, 2007). The findings showed that children in the experimental group who participated in the PMYC program not only had higher pre-teaching scores (given after the intervention program) but also showed higher pre- to post-teaching improvement than did the control group.

2.2.2. Computerized CMB-Analogies test

For this study we developed a computerized version of the CMB Analogies test in order to be able to run it as a 2D multimedia computer application using a mouse and screen interface as well as a 3D Immersive Virtual Reality world using a Head Mounted Display interface (HMD) (Fig. 3).

We conducted a pilot study in order to test the suitability of the hardware and software for young children use. Following the pilot study we improved the instruments, and added an introductory stage to familiarize the children with the HMD and the 3D environment (e.g., up, down, left, right and rotation). The introductory stage was designed to take 10 min, and included the following elements: orientation in the 3D IVR environment, acquaintance with and adjustment to the HMD interface, exercising selection of blocks from a repository and manipulating their location on the digital board, and exercising moves and other features in the virtual environment with a mouse while the HMD is on the subject's head (Fig. 3).

2.2.3. Virtual worlds

The first screen from which the DA procedure began included a grey, flat, square board with black squares painted on its four sides (hereafter, windows).

Fig. 3. A child wearing an HMD during a DA procedure.

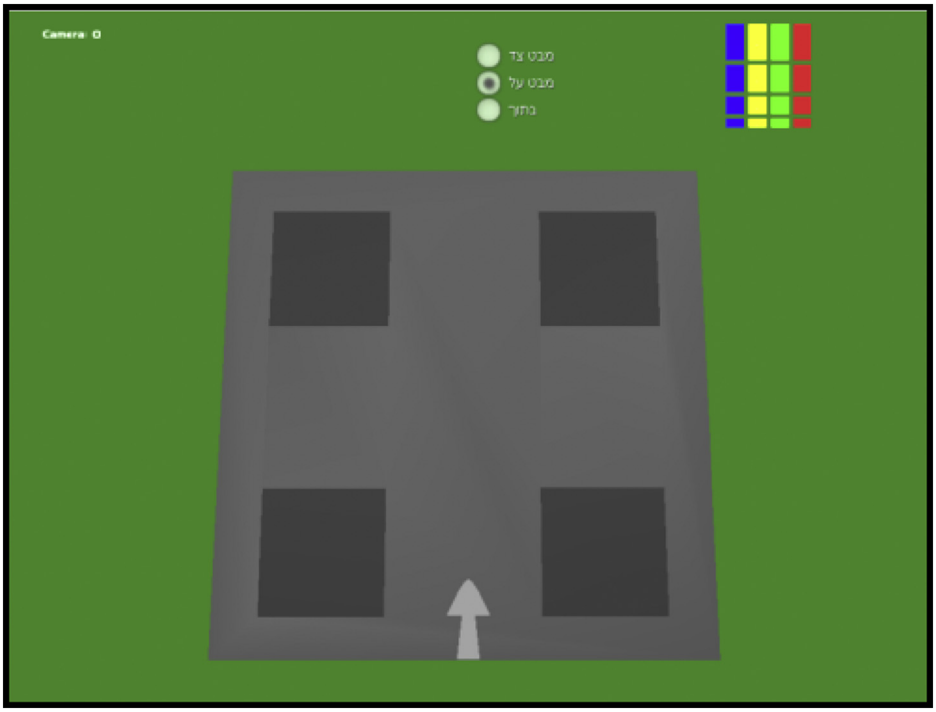

Fig. 4. The opening screen to the Computerized Virtual World in the 2D and 3D IVR environments.

In three windows (i.e., top-left, top-right, bottom-right) are representations of the colored wooden blocks, as dictated in each problem. In the front part of the board was a picture of a wooden arrow, which served as a permanent reference point to the front of the problem (the side closest to the child, on the bottom of the screen), and to its opening (Fig. 4). Each screen included a storage bin of the represented blocks located on the upper-right side of the screen in four colors (blue, green, red and yellow) that were arranged side by side by height (from highest to lowest; total of 16 blocks). The original storehouse of the original test included 64 blocks. In order not to clutter the virtual reality world with so many blocks we designed a feature that by pressing on the right block in the storehouse, the participant received 4 other blocks of the same color.

The computer application made it possible to observe the problem from three angles: *top*, *side*, and *within* (imagining a situation in which the child being examined is standing in the center of the board and is looking around). The starting point was the top angle. We placed three buttons in the upper center of the screen, and by pressing any one of them one could shift from one to any other angle of observation on the problem. In addition, the computer program was designed so that it would be possible to make the problem turn on a 360° horizontal axis (which enables observation from several points of view) and at an angle of 45° on a vertical (up and down) axis. In Fig. 5 there is an example of an analogical problem from different angles: top, front, within and 180° rotation.

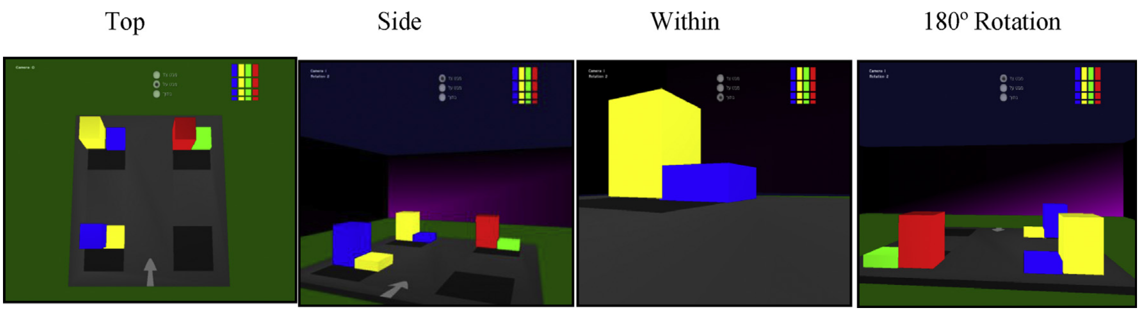

Fig. 5. Representation of a problem (TR2-B) in a Virtual Board as seen from different angles.

2.3. Procedure

This study included two measurements that were administered two weeks apart. The first measurement included a DA of analogical reasoning. The DA procedure included pre-teaching (30 min), teaching (30 min), and post-teaching (30 min) stages. The DA was performed in a small quiet room assigned by the school; only one child was assessed at a time. A 5-min break was given between the stages. Many of the children enjoyed participating in the DA procedure and wanted to stay at the room and continue with the procedure during the break. Before starting the assessment, the examiner with all the study groups introduced himself/herself to the child and led the child through some warm-up exercises to familiarize him/her with the DA tools, concepts (height, number, color, location) and problem-solving rules based on to the CMB guidelines (Tzuriel, 1995). In the 2D and 3D computerized environments, the examiner explained the mouse-screen interface, and introduced the child to the buttons which enable movement and the buttons which enable to pick the blocks. The examiner also explained how to use the Head Mounted Display (HMD), how to move and orient oneself in the 3D IVR space. Some more time was given to adjust the HMD to the child, showing her/him how it enables immersion in the virtual space. In the control group, the examiner demonstrated to each child, individually, the solution of a sample problem before administering the pre-teaching test; no teaching stage was given before the post-teaching test. It is important to point out that the teaching stage was similar in all the experimental groups; i.e., the mediation strategies that the examiner monitored throughout the procedure with each child were similar in all the experimental groups. Naturally the teaching phase could not be identical in all experimental groups. Attempts however were made to equalize examiners' level of mediation, so that the main the main group differences in performance are attributed to the learning environment (Tangible Blocks, 2D and 3D IVR).

The second measurement of Analogies was carried out two weeks later using the Transfer problems of the CMB. The Transfer test was conducted individually using a standardized assessment procedure with a tangible board and blocks. The assessment was conducted in the same allocated small room of the testing stage. The administration of the transfer problems two weeks after the testing phase was carried out to control for memory effects and ensure that performance reflects internalization of the analogical reasoning. Thus, the transfer phase was different from the testing problems not only in terms of the nature of problems but also in terms of the time passed from the initial test phase. Performance of the transfer analogies reflects another facet of cognitive modifiability.

3. Results

3.1. Group differences on pre- to post-teaching improvement

The DA procedure yielded two main scores: Pre-teaching and post-teaching, each was based on sum score of the dimensions of color, height, number, and location of the CMB Analogy Subtest. The range of scores in each dimension was 0–14 and the total range of scores was 0–56. Cognitive modifiability is indicated by the level of improvement from pre- to post-teaching.

A repeated measures MANOVA of Group × Time (2 × 2) revealed a significant Time main effect, $F(1,113) = 241.77$, $p < 0.001$, $\eta^2 = 0.68$, indicating an improvement from pre- to post-teaching. The means and standard deviations of pre- and post-teaching scores as well as the Group × Time interaction are presented in Table 3. The interaction is presented in Fig. 6.

As can be seen in Table 3 and Fig. 6 the three experimental groups improved their performance from pre- to post-teaching whereas the control group showed no improvement. Post-hoc analysis revealed no significant difference among the four groups in the pre-teaching phase.

A post hoc analysis was carried out using ANOVA approach where group differences on pre- to post-teaching improvement of Analogies were analyzed for each pair. Each analysis yields for each pair an interaction indicating which group in the pair made better improvement. A Bonferroni correction was applied for these analyses. The findings revealed (see Table 4) that the control group, as expected, showed lower improvement than each of the three experimental groups. The 3D IVR group showed significantly higher improvement than the 2D group. The 2D and the Tangible Block groups showed almost the same improvement and the 3D IVR showed a slight better improvement than the Tangible Blocks group, though the difference did not reach a significance level.

Table 3
Means, standard deviations, and F statistics of the four groups in CMB analogies in pre- and post-teaching stages of the DA procedure.

	3D-IVR n = 36		2D n = 36		Tangible Blocks n = 24		Control n = 21		Group × Time	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	$F(3,113)$	Eta^2
M	2.58	10.72	4.02	9.75	4.70	10.45	4.00	4.19	25.18***	0.40
SD	3.27	3.89	3.36	2.87	4.49	3.20	4.42	3.57		

***$p < 0.001$.

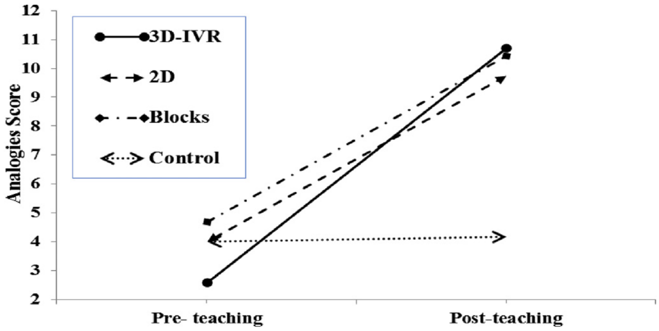

Fig. 6. CMB Analogies pre- and post-teaching scores in the four groups of the study.

Table 4
Comparison between pairs of the four study's groups in pre- and post-teaching phases.

Group × Time				
Group comparison	df	F	Eta^2	Mean difference
3–4	1.43	28.53**	0.40	173.08
2–4	1.55	49.11**	0.47	202.92
1–4	1.55	117.70**	0.68	418.96
2–3	1.58	0.00	0.00	0.00
1–3	1.58	5.88	0.09	41.08
1–2	1.70	9.89*	0.12	52.56

*$p < 0.05$, **$p < 0.01$.
Note. 1 = 3D-IVR, 2 = 2D, 3 = Tangible Blocks, 4 = Control.

3.2. *Group differences on the transfer analogies*

In order to test the hypothesis on the Transfer test, we performed a one-way ANOVA where the independent variable was Treatment and the dependent variable was the CMB Transfer Analogies score (see Table 5).

The findings show that the highest group was the 3D-IVR followed by the 2D, Tangible Blocks and Control. Post-hoc analysis using Scheffe's procedure ($p < 0.05$) indicated that the control group was the lowest and the 3D IVR group was the highest of all groups. The 2D and Tangible Blocks groups scored about the same.

4. Discussion

The goal of this study was to examine the influences of a teaching process which takes place in a computerized DA procedure and especially in 3D IVR on children's cognitive modifiability in the domain of analogical reasoning. We asked whether a DA procedure, conducted in computerized environments, would better reflect the child's cognitive modifiability than a standardized tangible blocks situation.

This goal was based on a number of studies addressing the issue of developing thinking skills in computerized environment (Dede, 2005), and on findings of various studies based on DA of young children using analogical reasoning tests (Tzuriel, 2001, 2011, 2013). Our research is the first known in which cognitive modifiability of children is assessed in a 3D IVR environment compared with computerized 2D and non-computerized tangible blocks environments. Our main hypothesis was that a 3D IVR environment would create the best conditions enhancing learning of analogical reasoning. As expected the findings support our hypothesis showing that children participating in the 3D IVR environment showed the highest cognitive modifiability especially on the transfer problems given two weeks after the end of the teaching phase. It seems that the conditions of the 3D IVR environment used synergistically with the MLE strategies applied by the examiner in the teaching phase helped the young children to internalize the analogical operation and use it later in more difficult problems than the

Table 5
Means, standard deviations, and F statistics of the four groups in CMB-Analogies Transfer scores.

Treatment groups							
		3D-IVR	2D	Tangible Blocks	Control	F(3,113)	η^2
Transfer Analogies	M	5.32	3.59	3.50	1.47	17.34***	0.32
	SD	2.47	1.76	2.02	1.20		

***$p < 0.001$.

original analogies taught. The improvement of the 3D IVR group was beyond the 2D computerized environment. These findings are supported by findings of other 3D IVR studies conducted with older children using analogies (e.g., Passig & Miler, 2014). Passig and Miler (2014) reported that children who learned analogies in a 3D IVR environment preserved their learning strategies better than did children who practiced analogies by looking at pictures.

The question that these findings raise is what exactly is triggered by the IVR 3D environment that makes children internalize better the analogy operation? One possible explanation for this lies in the manner in which one uses virtual reality. The improvement of cognitive skills stems probably from the possibilities embedded within this technology which presents abstract concepts through a concrete, visual, three dimensional experiences. It is well established from earlier research that when analogies are presented to children by means which they are familiar with and which they deem concretely significant; they deal with them successfully (Goswami, 1992; Halford, 1993). The IVR 3D technology presents children with possibilities of exploring the information from different angels, actively constructing and manipulating points of view and innovative perspectives thus allowing children to assimilate the relations between the problem components and lead them to make better deduction from the presented problem.

The virtual visual information presumably stimulated a unique spatial representation of the analogy elements. Spatial representation is best thought of as a domain of skills rather than a single ability and includes skills such as mental rotation, spatial visualization, and the ability to deal with two-dimensional images of a hypothetical two- or three-dimensions. Some support may be found in research of computer game playing and development of spatial skills (Greenfield, Brannon, and Lohr, 1994; Okagaki & Frensch, 1994; Subrahmanyam & Greenfield, 1996). McClurg and Chaille (1987) found for example that computer games helped children improve their mental rotation and spatial representation skills. The enhanced spatial representation helped the children later to solve analogies. It seems that the developed visual ability transferred, as the dual coding theory suggests (Paivio, 1991) to perceptual information retrieved from memory while addressing an analogy.

Much of the research on the impact of computer games on cognitive skills has only measured the effects of computer game playing immediately after practice, and does not address questions about the cumulative impact of interactive games on cognition. Nonetheless, selective increases in nonverbal or performance IQ (Flynn, 1994, 1999) scores during the last century seem to relate, in part, to the proliferation of imagery and electronic technologies in the environment that has occurred in this period of time. Many computer games develop the same skills that are tested in nonverbal IQ tests such as the Wechsler and the Stanford-Binet found improvements in the skill of spatial visualization among males as a result of playing the video game Tetris. The skill of spatial visualization developed by the video game Tetris coincides with development of the ability to solve the Object Assembly subtest of the Wechsler intelligence tests for children and adults.

An additional possible explanation for the effectiveness of the IVR 3D environment is related to the inhibitory control and working memory aspects of executive function which explain analogical reasoning capacity in children (Richland & Burchinal, 2013; Richland et al., 2006; Thibaut et al., 2010). It is possible that the IVR 3D environment allows the children to better, memorize and manipulate the information held in their mental schem and grasp the rules of transformation by assisting them to observe a problem from a wide angle and different perspectives. With this mode of perception they can make a systematic search for the blocks most appropriate for solving the analogy and improve their ability to think simultaneously along a number of dimensions as required by the CMB analogies.

Yet another explanation for our findings could be related to the geometric nature of the objects that are included in the virtual worlds simulated in this study. For example, Passig and Eden (2002) reported that students who practiced rotation of geometric objects in a 3D IVR environment showed higher cognitive performance over students who practiced the same objects in a non-computerized environment. Similarly, in the present study the simulation of geometric blocks in a 3D IVR environment contributed to an accurate perception and detailed input of the perceptual stimuli and consequently brought to better conceptual solution of the abstract analogical problem. It is interesting to note here that some researchers from the Russian school of thought (i.e., Davydov, 1990; Galperin, 1969, 1982; Karpov, 2003a, 2003b) emphasize the need to teach general problem-solving strategies rather than to provide specific concrete examples. The process of mastery of a new strategy was actually conceived as an *internalization process*, in which children first use the strategy to solve problems at the visual-motor level, and then they become able to use it at a perceptual level and finally at the symbolic level (Galperin, 1969, 1982). Karpov (2003a, 2003b) has shown that not all children need to be taught a new strategy initially at the visual-motor level and that some children are able to grasp the abstract rule and solve problems afterwards at perceptual and even symbolic levels. He claims, though, that most children are in need of being taught a new strategy initially at a perceptual or even visual-motor level before they become able to perform this strategy at a symbolic (conceptual) level. We believe, however, that this aspect should be further examined in future studies in order to deepen our understanding of the effects of IVR 3D environment which serves as a vehicle for higher level of conceptualization.

It should be emphasized though that the effectiveness of the IVR 3D environment cannot be separated from the impact of the MLE strategies used. What works so efficiently is the interface between the two components—“the whole is more than the sum of parts”.

5. Summary

The findings of this research have both theoretical and practical implications. From a theoretical point of view, we learned that integrating a computerized 3D IVR environment synergistically with MLE strategies within a DA procedure creates a computer-mediator-learner "intellectual partnership". This partnership, it seems, generates a unique perceptual experience that broadens the child's world of mental images, it strengthens the internalization of the MLE principles and contributes to her/his cognitive achievements. Therefore, one can also say that 3D IVR technology is an important and appropriate environment for assessment. It seems that children's cognitive modifiability is influenced not only by the mode of representation in which the teaching is carried out, by also by the degree of immersion and partnership of children with the computer and by the mediation strategies. We believe that these two points are important contribution to the DA approach as well as to computerized techniques of teaching.

Our findings have brought to light a wide range of clinical and educational applications of DA and 3D IVR technology. In further studies we suggest to investigate how cognitive modifiability assessed in IVR 3D environment contributes to prediction of achievements in school subject matters as well as to achievements in outside of classroom settings. We believe that novel additional set of diagnostic instruments that has been made available to educational diagnosticians will provide clinicians with better procedures of assessment and of teaching techniques. These procedures reflect better the child's cognitive modifiability and consequently enable more accurate intervention procedures. In the assessment procedures, it will be possible to alter the traditional assessment tools in exchange for rich and versatile IVR 3D worlds that will open up new possibilities for a wide range of cognitive diagnostic procedures and for a wide range of populations.

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