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THREE-DIMENSIONALITY AS AN EFFECTIVE MODE OF REPRESENTATION FOR EXPRESSING SEQUENTIAL TIME PERCEPTION

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ABSTRACT

The process of developing concepts of time continues from age 5 to 11 years (Zakay, 1998). This study sought the representation mode in which children could best express time concepts, especially the proper arrangement of events in a logical and temporal order. Usually, temporal order is examined and taught by 2D (2-dimensional) pictorial scripts. Using Bruner's (1973, 1986, 1990) representation stages, we tested the comparative effectiveness of VR (Virtual Reality) as a mode of representation on children's conception of sequential time with the pictorial representation mode, the oral, and textual modes. The study involved 65 participants, aged 4 to 10, in 2 groups: kindergarten and school children. The study examined their ability to arrange episodes of a scenario in which a temporal order exists, using the different modes of representation. The findings demonstrate substantial differences in the temporal order arrangement between the modes of representation. In the 3D VR representation, the subjects had a smaller number of errors than in the other representations. These findings suggest that even though the pictorial mode is the most common way of examining and expressing temporal sequence, we should establish new ways of presenting sequencing so that children will be better able to achieve their full cognitive and academic potential.

INTRODUCTION

Time is a central and vital dimension in our lives. Research has made distinctions between different kinds of time, according to the way in which people experience them: physical time is measured by clocks, biological time represents the occurrence of specific biological processes, while psychological time is experienced by the conscious self (Zakay, 1998). It is the latter which was the focus of this study.

The process of the development of a concept of time is a gradual one, which takes place after the child has acquired a sense of space (Clark, Marschark, & Karchmer, 2001). As infants have yet to acquire a developed ability to remember, something which is a precondition to the creation of an awareness of past, present, and future, the researchers assume that during early childhood time is experienced as discrete moments, and the young child lives in a world which has only one stage of time: the present. By the end of his fifth year, the child has learned the difference between past, future, and present, but has yet to acquire a complete perception of time. For example, "I'm four, my brother's five, and next year we will be the same age." Time orientation is acquired about age seven. A full grasp of all the dimensions of time, including historical time, is attained only at the age of puberty (Zakay, 1998).

Conventional perception of time has been studied in two areas, the *duration* and the *sequence* of time. This study focused on the sequence of time, which is defined as the occurrence of events, one after the other, in intervals of days, weeks, months, and years, as well as the arrangement of continuums of events, according to the order in which they happened (Piaget, 1926).

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Studies in time perception have touched on the question of the age at which a child is able to unify the images in different episodes to a single image, and to understand the meaning of the time continuum. Some studies found that unification of the images occurs only at about age five (Bornens, 1990). Other studies focused on the developmental continuum of the perception of time in children. The findings indicate that there is a developmental continuum from ages 2 to 8 years (Ge, Fuxi, & Fan, 1984; O'Connell & Gerard, 1985).

Various studies also tried to look at whether children deduce logical connections between actions, or do they depend on their general knowledge in arranging a continuum of events? The findings indicate that in simple assignments and events there exist the same developmental model with very young children as well as with children between the ages of 4 to 6 years and that mostly they rely on their general knowledge (Carni & French, 1984; Fivush & Mandler, 1985; French, 1989).

The aim of this study was to test whether the representation modality is having any effect on the quality of the logical connections that the children are doing in arranging a continuum of events. This quality was tested by the amount of errors the child is doing in the process of arranging the events.

REPRESENTATION MODALITIES

Despite the great importance of time perception, the educational system in most countries doesn't teach it as such. *Time* is an abstract concept, and is based on representational thinking. One who is looking at a series of pictures of an event is expected to understand the meaning of every point in time, to use his/her life experience to fill in the gaps, and to put together a continuum of events. In order to do so, one needs the ability to make sophisticated abstractions (Bornens, 1990).

Essentially, the representation is something which stands for something else; a hint of the existence of two separate worlds: the represented world and the representing world. The representation is not an exact copy of that which is represented, but a version of it. For that reason, there is a certain amount of abstraction in every representation (Denis, 1991; McShane, 1991). Bruner (1973, 1986, 1990) enumerates three representational systems which serve as an important means of mediation between the child's knowledge of the world and the linguistic representation of this knowledge, which appear to the child in a developmental continuum:

- *The system of enactive representation*—In their first years, children represent objects by means of immediate, sensory perception, while involving motor or other responses in taking control of the environment (e.g., riding a bicycle or tying a knot). This system reflects the child's experience and method of investigating an event while actually carrying out the activity, or making a close simulation thereof.
- *The system of iconic representation*—This system demands the use of mental representations which represent certain objects or events, and is based on frontal images such as pictures, models, or sketches. This system is important for acquiring the ability to distance oneself from enactive representation and to get closer to symbolic representation.
- *The system of symbolic representation*—This system uses symbols as information codes, and allows for the arbitrary representation of reality via written or spoken language.

Through the years, a number of studies have been carried out to examine the level of the effectiveness of a variety of modes of representation. Some of the studies compared isolated modes of representation–the verbal mode vs. the visual mode (Gobbo, 1990; Pine & Grimes, 1985; Vasu & Howe, 1989), the written mode vs. the auditory mode (Gobbo, 1987), and the video mode vs. the computerized mode (Beykirch, 1990). Most of these studies seem to conclude that the visual representation mode is preferable and more effective in expressing ideas. Other studies investigated dual representational modes, and compared various combinations, such as verbal-visual modes or auditory-visual modes (Mousavi, Low, & Sweller, 1995; Ottaviani & Black, 1994; Vasu & Howe, 1989). These studies concluded that a combination of representation modes improves the subjects' achievements, when compared with subjects who used a single representation mode.

The current study aimed at discovering the most effective representation mode with which children could express time concepts. Temporal order is usually examined and taught by means of 2D pictorial teaching aids. Following Bruner's representational stages (1973, 1986, 1990), we tried to determine whether children would grasp and express temporal order differently in different modes of representation.

This study also compared 3D representation with three commonly used representations—pictorial, textual, and spoken in order to seek the most effective representation mode for expressing sequential time perception for children.

To the best of our knowledge, this study is one of the first to use VR as a new mode of representation and expression. Many studies, over the years, have examined VR technology from different perspectives, but few have tried to see whether it could serve as a mode of representation. One of these studies examined the influence of two degrees of spatial skill (low and high) with two forms of representation—VR vs. the conventional computer, on the ability of carrying out the task of rotating pictures. The ability was measured by the response time and degree of accuracy. VR was found to be significantly a more effective mode of representation than the conventional computer. The researchers attribute these results directly to the mode of representation (Manrique, 1997). The current study, therefore, re-examined the idea that VR is a new mode of representation and expression by testing how well children will perceive and express the concept of time while compared to other modes of representation.

PARTICIPANTS AND PROCEDURE

Sixty five participants took part in this study. They were divided into two age groups: kindergarten and school-age children. We examined their ability to arrange episodes of a scenario in which a temporal order exists, using the different modes of representation. Each participant received four scrambled episodes of a single scenario. Each participant was tested with three modes of representation and in total received three scenarios. In order to verify that sequencing correctly indeed represents a conceptual understanding of the scenario, we have provided the participant with a fifth episode with a question mark for them to continue the scenario. The participants that arranged the episodes in the right sequence and projected the correct next episode were considered to fulfill the task. For example, baking a cake scenario has been divided into four different episodes: the first episode depicted the need to put the materials into a bowl. The second depicted the need to flatten the dough. Following, the need to put the cake in the oven, and finally the outcome should be a baked cake. The fifth episode could have been eating the cake. This scenario has a temporal order in which one can't put the cake in the oven and only then put the materials into a bowl.

The age of the participants ranged from 4 to 10 years old (Table 1). These ages reflected studies indicating that children of five and six years are able to organize events they were presented within an inclusive context of space and time (Brown & Hurtig, 1983; Hedberg & Stoel-Gammon, 1986). As far as we know today, time perception starts developing at the age of 5 to 6. It fully materializes around the age of 12 (Zakay, 1998). This study investigated such a wide range of ages in order to make verify whether there are difference and what kind of differences exist in expressing and perceiving sequential time in each year of that range.

Four research tools were used in the current study to examine the most effective mode of representation:

- *Pictorial representation*—Six scenarios were chosen (three simple and three complex) which had temporal sequence and a cause and effect relationship. They were presented to the children in colorful cartoon drawings, four to five pictures for each scenario.
- *Written representation*—A written version was developed for the previous pictorial scenario. One or two lines were written for each picture, which gave a brief description of what is shown in the picture. We did not make use of any time-related or cause and effect words (connections) which would hint at temporal sequence or causality, such as before, after, then, etc.
- *Aural representation*—The written representational text was read to the children aloud clearly.
- *Immersive 3D VR with Head Mounted Display*—The scenarios which were drawn in pictures were processed into three-dimensional simulations. The virtual representation was both visual and auditory.

The initial three representation modes were chosen because they are the most commonly used in the educational system, as well as in the IQ tests—especially the pictorial representation (Such as the Kaufman Assessment Battery for Children K-ABC; Kaufman & Kaufman, 1983; Wechsler WISC-R Intelligence Scale for Children; Wechsler, 1974).

Table 1. Distribution of Participants According to Gender and Age

		Participants (n = 65)	
Characteristics	Values	N	%
Gender	Boys	37	56.9
	Girls	28	43.1
School setting	Kindergarten	42	64.6
	School	23	35.4

This study was organized according to Script Theory, developed by Schank and Abelson (1977). It included 6 scripts adapted to the different modes of representation, creating a total of 30 scripts. The temporal-order abilities of the participants were measured by the number of errors in the arrangement of the events in a logical order.

In order to avoid the familiarity with the story lines in the different modes of representations, the children received different scripts for each mode of representation. The scripts were validated by experts to have a similar level of difficulty. The scripts were then distributed to the children randomly. The scripts developed in VR had the same number of clues that the story lines in the other modes of representations. The only difference was the three-dimensionality and obviously the immersive and interactive aspects that characterize 3D immersive VR.

Each participant was tested in all modes of representations. The scripts and the order of modes of representations were different for each child. For example, a child has been tested in script A with pictorial representation, then in script C with written representation, following in script B with 3D representation and at the end in script C with aural representation. Another child has been tested in script C with 3D representation, then in script A with aural representation and so forth. This way we have avoided the issue of familiarity with the story lines in the different modes of representations and the effect of the research tool was neutralized.

VIRTUAL WORLDS

The main screen consisted of an entry to six virtual worlds—three for the younger group, and three for the older group. There was an entry screen for each virtual world. On each entry screen there was a picture which stood for a scenario, as well as the title of the story. On the right were separate pictures, each one representing a scene from the scenario (Figure 1).

The pictures were not arranged in logical order, but together, placed in proper sequence, they create a story which has temporal sequence. Clicking on a picture brings the user into the virtual world of a specific scene. The user can then manipulate the objects of the scene in 3D audio-visual and immersive environment. The manipulation was unique since the immersion in the 3D worlds demanded a much active role in the virtual environment. For example, in the baking episode, the participants could break the eggs, spill or pour the milk, etc. The vast possibilities of manipulation within a scenario are a unique feature of VR and therefore are considered to be highly active.

In order to test the child's ability to arrange the pictures in the proper order, we developed a screen for arranging a scenario (Figure 2). It was made up of four to five green squares. On each square there was a number, and small red circles for the visual identification of numbers for children who were not yet able to identify numbers. Four pictures belonging to the scenario appeared on the bottom of the

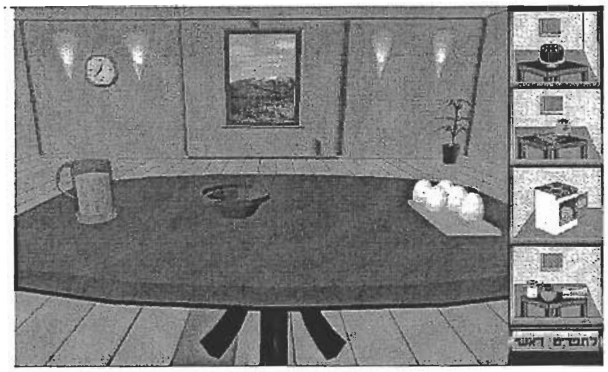

Figure 1. One of the episodes in a virtual world depicting the process of baking a cake.

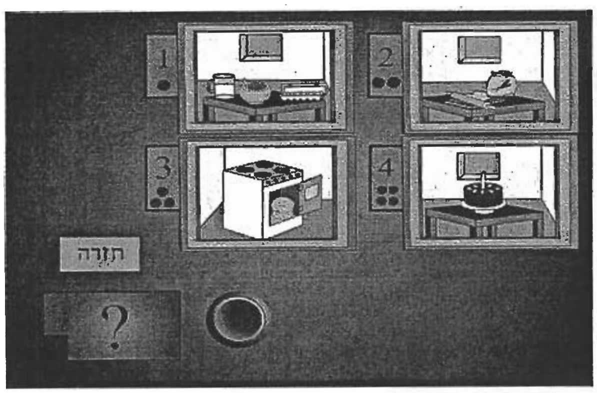

Figure 2. One of the episodes in a virtual world depicting the process of baking a cake.

screen. The child had to drag the pictures with the mouse, and arrange them according to the correct time sequence on the green squares. On finishing, the child would press the red operating key (Figure 3), and would then watch the movie he had created, according to the temporal order he had dictated.

RESULTS

This study was designed to compare the effectiveness of a 3D virtual representation mode with other 2D and audio-visual representation modes. It was designed to test which is the most effective mode of representation for the children to

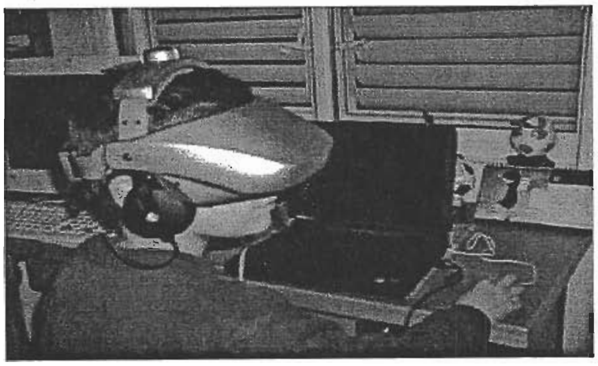

Figure 3. A participant in a virtual world.

perceive and express temporal sequence. The effectiveness was measured by the number of errors recorded while completing the tasks in the three modes we have tested: pictorial, aural, and virtual representation.

In Simple Effects analyses a significant difference was found between the three means of representation, $F(2, 128) = 10.92$; $p < .001$. In Table 2, one can see that the largest number of errors is in the pictorial representation, $M = 2.90$; $SD = 2.86$, the second largest number of errors is in the aural representation, $M = 2.83$; $SD = 3.16$, and the smallest number of errors is in the VR representation, $M = 1.24$; $SD = 0.33$.

The study involved two age groups that correspond to the range of ages through which one develops time perception. The aim was to test whether there are any differences in perceiving and expressing temporal sequence with regard to the modes of representation in these age groups. Figure 4 illustrates the number of errors made in expressing temporal sequence distributed by age group—kindergarten children and school-age children.

Figure 4 points out that kindergarten children made more errors in expressing temporal sequence than did school-age children, especially with the aural

Table 2. Averages and Standard Deviations of the Number of Errors

	Participants (n = 65)	
Representation modes	*M*	*SD*
Pictorial	2.90	2.84
Aural	2.83	3.16
3D VR	1.24	0.33

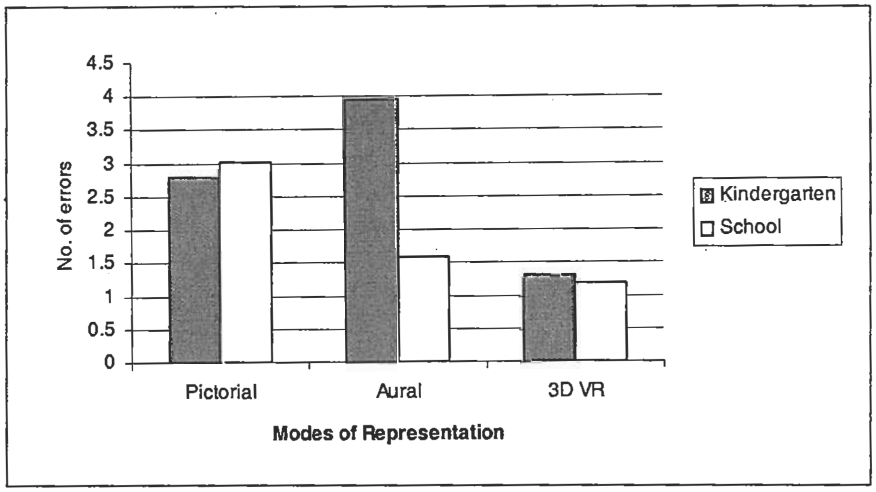

Figure 4. Average number of errors in temporal sequence made by kindergarten children vs. school-age children.

representation. In both of the age groups, the smallest number of errors was expressed with VR. This study tested also the written representation mode with the school-age children. In this case, the written representation was found to generate the highest number of errors: $M = 4.68$; $SD = 1.25$.

We performed a MANOVA analysis in order to see if there were differences in perception of temporal sequence according to gender. No significant difference was found: $F(4, 57) = 1.64$; $p > .05$.

These findings point that there is a difference between expressing and perceiving temporal sequence with 3D VR and other forms of representations. The participants faired better with the 3D VR representation compared to the other modes. The least effective mode was the written one, and the pictorial mode was also ineffectual. This suggests that the pictorial modality may not be as easy or effective as one might expect.

These findings suggest that even though the pictorial mode is the most widely used form for perceiving, expressing, and examining temporal sequence, we should look for other new ways with which to express and evaluate temporal sequencing, that way children will be able to better fulfill their cognitive and academic potential.

DISCUSSION

Over the years, children's ability to perceive temporal sequence has been examined quite in a variety of studies (Fivush & Mandler, 1985; French, 1989;

Fujisaki, 1998; O'Connell & Gerard, 1985; and others). To the best of our knowledge, all of the studies used 2D pictorial representation to test and improve temporal sequence. This study is different in assuming that children's achievements are dependent on the modes of representation in use, and that immersive 3D is a more effective representation mode to perceive and express temporal sequence. Using that mode, children are able to make full realization of their cognitive ability.

As far as we know, this study is the first to examine the perception of time by means of VR. The significant efficacy of VR as a representation mode suggests that children could express themselves effectively with 3D VR which could introduce a new field for research in the future.

It seems that these findings suggest that VR is more than a teaching aide. It might present a new kind of a tool with which one can express perceptions one couldn't with other modes of representations (Heled, 2004). Some already suggested (Mintz & Nachmias, 1998) that computerized imaging is of very great importance in making a representation of the complex world in which we live. By means of 3D VR, we can study abstract concepts which have hitherto been inaccessible to investigation, and can translate abstract perceptions into much more understandable visual representations. VR has been studied from various angles, but only a few attempted to answer the question: can this technology serve as a mode of representation? Calvert (1999) pointed out that simulation by means of 3D VR expands the limits of representation of the personal interactive interface while it enables enactive coding, as does the iconic and symbolic coding of content. Manrique (1997) also pointed out the technological advantages of VR as a preferred form of representation. In the context of the present study, therefore, there are a number of ways of explaining these advantages.

One explanation is tied to the ability of this technology to make the abstract more concrete, thereby making it easier to perceive time. Mintz and Nachmias (1998) showed that a visual environment on the computer screen, which can be altered and controlled by the viewer, is likely to provide the child with a tool with whose help he/she will act and gain experience in an intuitive way, in studying concepts which until now had been considered too abstract and complex. On the more so in VR, various studies in the field have already found that immersion improves the sensory interface, and improves the ability to understand abstract concepts by making them more concrete (Darrow, 1995; Osberg, 1995; Passig & Eden, 2000).

Time is an abstract concept, and is based on representational thinking. A person who is looking at a series of pictures of an event which is developing over time is supposed to understand the meaning of each point in time, to fill in the gaps from his/her own experience, and to construct a continuum of events which develops in time. In order to do this, the ability to generate abstractions is essential (Bornens, 1990). The participants were immersed into the 3D scenario and therefore, to a certain extent, felt that they were a part of it. In this way, abstract time became less foggy of a concept, and more concrete.

Another explanation touches on the interactivity of VR, and on its ability to cause the participants to be especially active. There is a high level of similarity to life and of 3D immersion, which enables the participant to be part of the virtual world. It is a kind of expansion of the existing reality, in which a person can hear, see, touch, and communicate with objects and images. This method enables the participant to become an active part of the environment, and not solely a passive observer (Barab, Hay, Barnett, & Squire, 2001; Bricken & Byrne, 1992; Harper, Hedberg, & Wright, 2000; Heim, 1992; Osberg, 1995; and many others). It may suggest that children need a more active representation and expression mode in order to attain a higher level of abstraction.

CONCLUSION

To the best of our knowledge, the literature doesn't record other attempts to verify whether time perception is dependent on the mode of expression being employed. Therefore, the results of this study could open a new venue of research in order to better understand the potential and pitfalls of the modes of representation we use in educating our children.

This study, above all, suggests that virtual reality technology is an important and efficient mode of representation in attaining a higher level of abstraction when compared with other modes.

If indeed it would be validated in future studies, we believe that these results could turn out to be breaking news for educators. We hope, nonetheless, that this initial evidence would motivate curriculum planners to introduce VR in the curriculum and help children in using their cognitive abilities in a most rewarding way.

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