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EXTENDED ABSTRACT

Spatial problem solving: assembling three-dimensional puzzles in real and virtual environments

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Introduction

There exist many varieties of puzzles, which are in continuous evolution. They are usually classified as "mechanical puzzles" (e.g., 14-15 Puzzle, 15 Puzzle, Rubik's Cube, Rubik's Magic), "wire puzzles" (e.g., Heart and Arrow Puzzle, Chinese Rings Puzzle), or "dissection puzzles", which require assembling objects in two dimensions (e.g., Tangram) or three dimensions (e.g., Soma Cubes, Bedlham Cube).

With the development of informatics, new sorts of puzzles have been introduced, such as the "maze type puzzles" (e.g., Pacman, Rogue (Hack), Doom, Counter Strike). In fact, there are no "strict" rules for classifying puzzles in these categories. For instance, Tetris shares characteristics of several of them. It is based on the concept of assembling pieces (as the dissection puzzles), but it is also a computerized puzzle with time constraints.

We are interested in the assembling of three-dimensional (3D) puzzles. We have selected a puzzle similar to the Soma Cubes. It is made of seven blocks of various shapes which have to be assembled to form a cube. Our objective was first to conduct an empirical study, and then to develop an experiment in a virtual environment. We were interested in the cognitive processes involved in solving the problem, with the objective of proposing methods of assistance for tasks involving the manipulation of 3D puzzles in virtual environments.

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The tasks of assembling 3D objects belong to the wider class of problem solving tasks. The operating agent has to build an anticipatory representation of a to-be-attained state of affairs, while generating strategies to reach that objective. Problem solving is illustrated by every situation where from the outset an agent does not have an obvious already available procedure to reach the final objective (cf. Newell and Simon 1972). One thus distinguishes between two sets of processes: the processes by which an agent builds a representation of the goal, and those by which a plan of action for attaining the goal is built and implemented.

Two broad classes of space-related problems are typically contrasted: those involving large-scale environments calling for navigation (e.g., Denis and Loomis 2007) and those involving the perception and manipulation of small-scale configurations of objects, such as those where individual elements must be combined to form larger configurations (e.g., Butler 1994). In the tasks that belong to the first class, the agents have to typically control the movements of an object (a person moving in space) through a set of objects whose topography is fixed. On the contrary, in the tasks of the second class, the agents have to control and modify the spatial arrangement of the objects relative to one another.

Previous research has shown that the users of virtual reality systems experience difficulty in operating within these systems and have poor performance when manipulating the objects displayed by the virtual reality devices. The current approaches to provide users with interactive tools are focusing on the realism of the perceptual or motor experiences, or on the use of metaphors for interaction (e.g., Bowman et al. 2002, 2005). This is why we propose an analytical approach based on the activity in the real world before moving to virtual worlds. Different interfaces can have different affordances and differently impact the way the users visualize the problem (cf. Norman 1990). This claim can further be extended on to the users' performance and even their strategies.

Method

Participants were invited to build a cube using seven blocks of various sizes, shapes, and colors. The experiment was intended as a first step in comparing puzzle construction in real and computerized (virtual) environments. The ultimate objective is to propose a user-centered approach and a task-centered interface.

Participants

The participants were 24 graduate students (10 women, 14 men), aged 23–39. Nineteen of them were right-handed, and the remaining five were left-handed.

Materials

The puzzle was made of a set of seven wooden blocks (see Fig. 1). Three of these blocks (all yellow) were of unique forms, and the remaining four were identical L-shaped blocks of four different colors (yellow, green, blue, red).

Procedure

The participants first completed two tests measuring their visuo-spatial abilities, the Minnesota Paper Form Board and the Mental Rotations Test. Then they completed the puzzle task. The participants were shown the seven blocks and were instructed to assemble them to build a cube. They were invited to verbalize their actions and strategies during the execution of the task. Their only constraint was to manipulate the cubes within the limits of a A3 zone in order to make possible video recording of their manipulations. At the end of the session, the participants were interviewed and their reports were recorded.

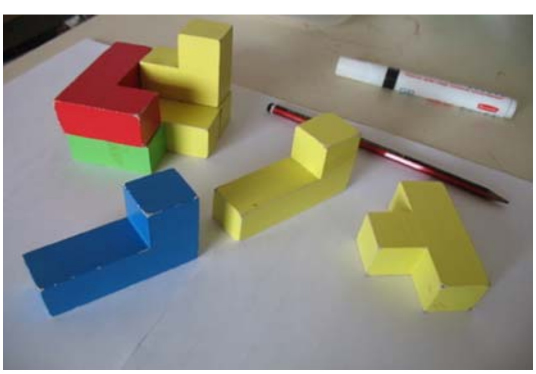

Fig. 1 The blocks used in the puzzle task

Results

A total of 17 participants (71%) did reach the correct solution. Interestingly, performance in the puzzle task was correlated with performance in the visuo-spatial tests. The participants who succeeded in solving the puzzle task had significantly higher scores on the tests than those who failed. There was no significant difference in the rate of success of men and women on the puzzle task, and no difference between right- and left-handed participants.

In the puzzle task, the participants tended to use some solutions, but all the possible solutions were not used. Those who succeeded made an average number of 3.9 attempts before reaching the solution (min = 1; max = 14). The participants' comments revealed that they spontaneously differentiated between what they called "easy" and "difficult" blocks. The same types of blocks were consistently judged "easy" or "difficult" by the participants. This classification was correlated with the perceived complexity of their shapes. There were five blocks perceived as "simple" and classified as "easy", while the remaining two blocks were both "complex" and "difficult".

Not a single participant solved the puzzle task by manipulating the most complex blocks at the end (although this type of solution does exist). We compared the frequency and time of use of the two types of blocks. Complex blocks tended more systematically to be included in the task solution at the beginning, whereas simple blocks tended to be added towards the end of the resolution more frequently.

We looked at the order in which the blocks were placed by the participants during their last attempt (i.e., the successful one). Table 1 shows which blocks (simple or complex) were placed at each step of the construction, for the successful final attempts of the 17 solvers. For instance, the first line of Column A shows that for the last attempt of the successful participants, a block classified as complex (difficult) was used 7 times as the first placed block out of 17. The frequency with which the complex blocks were used during the first three positioning actions was 24 (i.e., 7 + 9 + 8) out of 34 (a frequency of 71%), whereas for the last four positioning actions, the complex blocks were only used 10 times (1 + 3 + 5 + 1) out of 34 (a frequency of 29%).

Adopting the most adequate sequence of positioning actions for complex and simple blocks is a facilitating factor in approaching the solution. However, while the order of blocks is of primary importance, a further critical factor is the participants' capacity to posit the blocks in their respective correct orientations.

Table 1 Number of times where complex blocks (A) and simple blocks (B) were used during each of the positioning actions, for the 17 participants who succeeded

Positioning	A Number of times where complex blocks were used during each positioning action	B Number of times where simple blocks were used during each positioning action
1st	7	10
2nd	9	8
3rd	8	9
4th	1	16
5th	3	14
6th	5	12
7th (last)	1	16
Total	34	85

Discussion and perspectives

Our current objective is to go further and design an assisting device directing the user toward the solution. This assistance could be delivered at several levels, namely, micro (local) or macro levels, and should offer suggestions of the best strategies to implement.

The following factors are expected to contribute to solution attainment:

- the order in which the blocks are placed;
- the orientation of each block (by delineating the zone of the solution);
- the positioning of the blocks relative to one another.

These elements will be integrated in the system designed to assist the discovery of the solution. Visual cues suggesting the correct orientation of the selected blocks will also be included. The users will only be allowed to use the correct orientations. Lastly, the system will display an index of the current level of completion of the task.

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