Visualized Cues for Enhancing Spatial Ability Training in Virtual Reality

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ABSTRACT

There is a growing research interest in training spatial ability in Virtual Reality (VR), which could provide a fully interactive learning environment. However, existing spatial ability VR training systems lack cues to assist mental rotation and visualization. Learners may suffer from insufficient assistance to discover spatial reasoning rules in the training process. The aims of most visual cues for pedagogical purposes are to draw the viewer's attention, which can not meet the requirements of spatial training tasks. To address this issue, we propose three cues for learners to succeed in spatial tasks: color, rotation path, and circle. These visual cues provide supplementary spatial information and just-in-time explanations. They help distinguish the different parts of the solid, visualize the spatial information like rotation and direction, and emphasize the key points to solve the problems.

Keywords: Educational VR, Spatial Ability, Visual Cues.

Index Terms: Human-centered computing—Virtual Reality

1 Introduction and Background

Growing research suggests that Virtual Reality (VR) is an ideal environment for spatial ability training [1–4]. Due to its rich spatial interaction and simulated scenes, learners can be exposed to spatial tasks that other environments cannot support. Most studies offer learners an instruction of the system and interface to let them know the operations and interactions. Then the learners start to perform the tasks proposed in the system. The spatial tasks in VR are complex. Learners usually cannot receive sufficient assistance to discover spatial reasoning rules in the training process. Especially for low spatial ability learners, they may not know where to look, be distracted by irrelevant elements, and get lost in complex tasks. However, existing spatial ability VR training systems lack cues to assist mental rotation and visualization.

Adding visual cues such as color or arrows to direct attention in complex graphics or animation has been proved to be an effective way to improve learning [5]. Cues design in multimedia learning can assist learners to focus on critical parts of the task at the right time and place. The aims of most visual cues for pedagogical purposes are to draw the viewer's attention, which can not meet the requirements of spatial training tasks.

To address the aforementioned issue, we propose three cues for learners to succeed in spatial tasks in a spatial ability training system called FORSpatial [6]. FORSpatial provides 3D visualization, direct manipulation of virtual objects, and instant exercises with feedback. In FORSpatial, the tasks for learners are to observe and interact with shapes covered with several letters as patterns. These shapes can be folded into solids. Learners improve their spatial visualization and rotation through observation, interaction, and practice with these shapes and solids. However, there is still room to upgrade FORSpatial. Thus, we augment FORSpatial with color cue, rotation path cue, and circle cue. These cues help distinguish the different parts of the solid, visualize the spatial information like rotation and direction, and emphasize the key points to solve the problems. All the scenes and objects were developed with Unity [7] and 3Ds Max [8].

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2 Visualized Cues

We propose three cues to enhance spatial ability training system FORSpatial, including color cue, rotation path cue, and circle cue.

- **Color cue** As shown in figure 1 (top left), we augment the shapes with color cues to assist learners in distinguishing the faces and edges. Different colors are employed to distinguish the faces with and without letters and the facets with different letters. When learners fold the shape into solid, they may not map well the faces of the solid to the faces of the shape, especially after the solid is rotated to a different degree. Color cues make learners more easily recognize the letters on which faces, the discriminant edges, and the orientation of the faces. Furthermore, color cues helps learners direct their attention to important faces on the shape.

- **Rotation path cue** As shown in figure 1 (top middle), the rotation path cue refers to a cue for visualizing the direction of the rotation. When rotating the solid to the target direction, low spatial ability learners may be lost and can not obtain an identical orientation as the target solid. Through this cue, learners can view the moving spatial wake and construct a rotation strategy in mind. The rotation path cues use arrows to point out the movement steps and trajectories of solids. The cues and solids act synchronously, assisting learners to construct a rotation process of solids quickly.

- **Circle cue** As shown in figure 1 (top right), we propose a combination of circle cues and a detailed explanation to make the phenomena and problem visible. The circle cue refers a cue to highlight the differences between the target solid (see figure 1 (bottom middle)) and the distracted one (see figure 1 (bottom right)). This cue help emphasize the key points to solve the problems. Additionally, a detailed explanation is displayed so that learners can succeed in the practice.

3 Conclusion and Future Work

In this preliminary demo work, we present three visualized cues for enhancing spatial ability training in VR, including color cue, rotation path cue, and circle cue. The aims of these cues are beyond the goals of the common cues employed in learning, i.e., augmenting the display to draw viewers' attention to the most relevant parts in learning. They help distinguish the different parts of the solid, visualize the spatial information like rotation and direction, and emphasize the key points to solve the problems.

In our future work, first, we will test how these cues impact the improvement of learners' spatial ability and imagination, and enhance the acquisition of spatial reasoning skills. The cueing condition will be compared with the non-cue condition. Besides, learners

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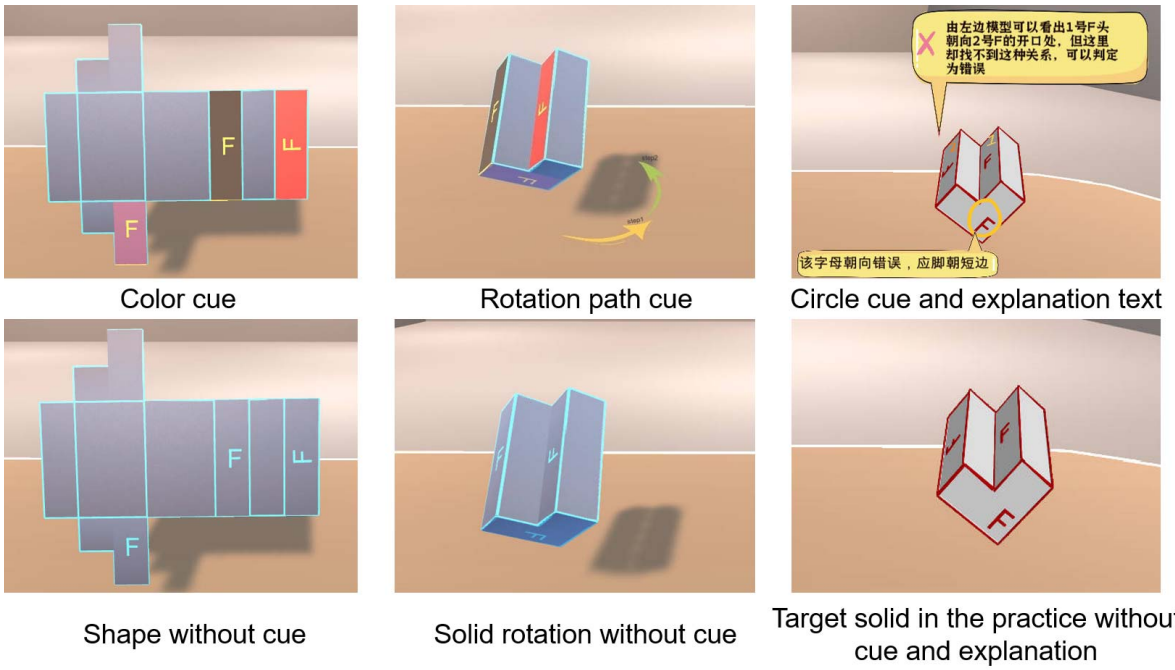

Figure 1: Three Visualized Cues. Top left: color cue. Top middle: rotation path cue. Top Right: circle cue. Bottom: the counterpart without cues.

will perform differently in immersive VR and less immersive VR (desktop VR). Thus, there would be a comparative study concerning immersion as a factor. Second, most of the current empirical studies of VR spatial training systems last a short time, like several hours, days, or at most two weeks. It is still unclear how the spatial training system works on the cognitive structure of learners during a long time of learning. We will investigate how cueing strategies in VR impact mental visualization and rotation for K-12 students. These cues can be applied to STEM education involving spatial tasks in VR learning environments, like anatomy, three-dimensional geometry, and physical experiments.

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References

[1] Jack Shen-Kuen Chang, Georgina Yeboah, Alison Doucette, Paul Clifton, Michael Nitsche, Timothy Welsh, and Ali Mazalek. Evaluating the effect of tangible virtual reality on spatial perspective taking ability. In *Proceedings of the 5th Symposium on Spatial User Interaction*, SUI '17, pages 68–77, New York, NY, USA, October 2017. Association for Computing Machinery.

[2] Elinda Ai-Lim Lee and Kok Wai Wong. Learning with desktop virtual reality: Low spatial ability learners are more positively affected. *Computers & Education*, 79:49–58, October 2014.

[3] Cheryl A. Cohen and Mary Hegarty. Visualizing cross sections: Training spatial thinking using interactive animations and virtual objects. *Learning and Individual Differences*, 33:63–71, 2014.

[4] Anahita Sanandaji, Cindy Grimm, and Ruth West. Inferring cross-sections of 3D objects: a 3D spatial ability test instrument for 3D volume segmentation. In *Proceedings of the ACM Symposium on Applied Perception*, pages 1–4, Cottbus Germany, September 2017. ACM.

[5] Jan L Plass, Richard E Mayer, and Bruce D Homer. *Handbook of game-based learning*. Mit Press, 2020.

[6] Yun Zhou, Tao Xu, Han Yang, and Shiqian Li. Improving spatial visualization and mental rotation using forspatial through shapes and letters in virtual environment. *IEEE transactions on Learning Technologies*. under review.

[7] Unity Developer Tools. Accessed: Jan. 2, 2021.

[8] AUTODESK Software 3Ds Max. Accessed: Jan. 2, 2021.