Spatial Reasoning in Minecraft: An Exploratory Study of In-Game Spatial Practices

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Abstract: Spatial reasoning is an important skillset that is malleable to training interventions. One possible context for intervention is the popular video game Minecraft. Minecraft encourages users to engage in spatial manipulation of 3D objects. However, few papers have chronicled any in-game practices that might evidence spatial reasoning, or how we might study its development through the game. In this paper, we report on 11 middle school students' spatial reasoning practices while playing Minecraft. We use audio and video data of student gameplay to delineate five in-game practices that align with spatial reasoning. We expand on a student case study, to explicate these practices. The identified practices may be beneficial for studying spatial reasoning development in game-based environments and contribute to a growing body of research on ways games support development of important and transferable skills.

Introduction

Over the past decade, Minecraft, a 3D sandbox game, has become a cultural phenomenon for youth globally. The open world game has sold over 176 million units as of May 2019. Educators are using Minecraft to teach a variety of subjects such as circuits, chemistry, mathematics, architecture, urban planning, and more (Lane, Yi, Guerrero, & Comins, 2017; Nebel, Schneider, & Rey, 2016). Blog posts and magazine articles have speculated about the potential of Minecraft to promote spatial reasoning skills (Kulman, 2016; Ossola, 2015). However, empirical evidence is needed to substantiate these speculations in terms of identifying in-games practices and measuring spatial skill development over time. In this paper, we address the first gap through an exploratory study of in-game practices pertaining to spatial reasoning. Concretely, we report on five spatial practices and situate those practices within a case study from a student that exhibited high spatial reasoning ability.

Spatial reasoning

Spatial reasoning, as discussed in the literature, represents an area of study that is constantly changing and the subject of debate (Buckley, Seery, & Canty, 2018). Many scholars have posited new definitions and models for what appropriately constitutes spatial reasoning (Buckley et al., 2018; Ramey & Uttal, 2017; Uttal et al., 2013). Consistent across these different definitions is the notion that spatial reasoning includes a variety of concepts that can be loosely grouped into spatial skills (the ability to visualize or manipulate 3D objects), perceptual factors (the ability to perceive and encode spatial information), and memory factors (how someone may remember spatial information) (Buckley et al., 2018). There are several tests for the different dimensions of spatial reasoning. Some common examples are mental slicing, mental folding, navigation, and mental rotation. For this study, we focus on mental rotation tasks which involve two key practices that also emerged as in Minecraft: spatial/visual anchors and visualizing the same object from multiple angles.

Spatial reasoning in context

While spatial reasoning tests are an asset to understanding student cognition, we are interested in observing the types of spatial practices that emerge during gameplay. As the aforementioned quotation notes, observing these practices can be quite challenging. One reason for this challenge is because spatial reasoning refers to an action that often takes place in someone's mind, without clear external indicators. Hence, a major contribution of this paper is to chronicle those practices and describe how they are substantiated in the context of Minecraft. Accordingly, our view of spatial reasoning is influenced by recent work on spatial reasoning in context and distributed spatial sensemaking (Ramey & Uttal, 2017). Spatial reasoning in context helps connect spatial reasoning to real-world situations. Specifically, spatial reasoning in context refers to the ways that individuals utilize spatial reasoning in everyday situations through actions and spoken utterances aimed at problem solving. Moreover, it highlights ways that individuals use spatial reasoning to solve everyday problems. We extend this idea to consider ways that spatial reasoning manifests in the everyday practices that students adopt in Minecraft. We refer to these different actions as spatial practices, which we articulate in more detail in later sections.

Methods

We collected data during two weeks of Minecraft summer camps. We conducted the free camps in partnership with a Title 1 middle school in a Midwestern city in the United States. The camps included 11 students ages 12 to 14 years old. One student was female, and the rest were male. All but one student was from an underrepresented minority or immigrant population.

Data collection

On the first day of the camp, participants completed a preliminary survey that included 21 questions about their prior experience with video games, Minecraft, and with construction kits like Legos or K'NEXs. Students then completed a Mental Rotation Test (MRT) (Peters et al., 1995), which presents students with 24 questions of different 3-D objects, represented in two dimensions. Participants must compare a target object to four other objects and identify which are the same and which are different. The team also collected video and logged data of each student and their gameplay experience through individual computer recording and whole room video.

Data analysis

The bulk of the analysis and discussion will focus on qualitative data. These analyses, which include the identification of spatial reasoning related practices, are derived using grounded theory (Glaser & Strauss, 1967) which involved repeated coding and observation of student videos. In coding the videos, we were specifically looking for actions that were relevant to spatial reasoning. Our ability to interpret user actions was heavily influenced by prior literature on educational games (Lane & Yi, 2017), spatial reasoning (Ramey & Uttal, 2017), and embodied cognition (Abrahamson, Shayan, Bakker, & Van Der Schaaf, 2016). This paper summarizes the observed practices and includes a case study of complex spatial reasoning in Minecraft.

Results

Spatial reasoning practices in Minecraft

Table 1 Summary of Spatial Practices Observed from Coding

Practices	Description
Taking a bird's eye view	The process of zooming out allows students to more easily see the relationship between different components of their design.
Building from multiple perspectives	Students frequently exhibit and practice mental rotation and flexibility by building from different perspectives or angles. For example, a student might start by building from the exterior of their building, but later move to adding blocks from the inside of the building.
Building while moving	Minecraft involves the ability to simultaneously move and build. To do this well, students need an understanding of how they are moving, and where to place subsequent blocks.
Counting	With the absence of a ruler, counting blocks provides a concrete means for comparing the dimensions of different portions of a build.
Spatial/Visual anchors	Building often requires the use of an anchor or a reference point. Once that point is established, students can base other portions of the design on that reference point.

Table 1 provides a summary of the spatial practices identified through coding of gameplay. For the purpose of this paper, we will focus on one class of these practices, spatial/visual anchors. Spatial/visual anchors sit at the crux of the spatial reasoning practices that students demonstrated through their actions. We consider spatial/visual anchors to be a type of attentional anchor (Abrahamson & Sánchez-García, 2016; Abrahamson et al., 2016). Attentional anchors refer to imagined or real structures that help the individual focus or constrain their attention. A canonical example of an attentional anchor can be found in juggling, where novices are encouraged to visualize a rectangular tower that rests directly in front of them. This imagined shape provides the juggler with a concise set of reference points or a single unified object that can decrease the complexity of juggling. However, whereas attentional anchors in Abrahamson & Sánchez-García, 2016 and Abrahamson et al., 2016 typically constitute non-visible objects, the spatial/visual anchors that we refer to can take on a mental or virtual representation. Additionally, they exist as both embedded and scaffolded (i.e. an object that will only be used temporarily and then destroyed) virtual anchors. The case study that follows provides a clearer description of these different spatial/visual anchors and how they present within Minecraft gameplay.

Case study

Our case study is from a student who received a high score on the spatial reasoning test and reported a high level of prior experience with Minecraft. The specific episode under consideration involves the student creating a mushroom tower with two other students. In this scenario, all students worked on their own computers in the same room. The students worked together to build the tower structure layer by layer, meaning they created the initial structure on the ground and gradually added additional levels. The next step was to make the base of the mushroom tower. The students attempt to do this, resulting in the red-brown perimeter that appears around the top of the base of the tower (Figure 1). However, as the reader will note, the structure lacks symmetry and does not match the contours of the tower. In order to correct this, the students create a scaffold to help them correct the design. The scaffold is a rectangle that sits around the top of the base tower (Figure 2). The rectangle ensures that the design will be symmetric. After creating the rectangle, the students add an additional support that connects the gray part of the tower to the brown portion that will be the base of the mushroom top. He notes that three blocks are needed to connect to two components. The student then goes to the other side of the tower and checks the distance between the tower and the brown rim – 2 blocks are needed. Upon doing so, they see that one side of their rectangle is too close to the tower and proceed to correct their design. After checking the different sides for dimensional consistency, the student uses the rectangle to symmetrically create the diagonals, which was the crux of the problem beforehand. Namely, the student counts how far from the corner the diagonal should start, and to which spot on the adjacent side it should end. After creating this diagonal, the student destroys that corner of the rectangle, and proceeds to the next corner. In this way, we see that the rectangle served the purpose of helping the student resolve symmetry across the different corners of the brown rim. The students first attempted to build the rim based on local perceptions of the design, but found that this was inefficient. Instead, with the addition of a rectangular scaffold, they introduced an easier way to complete the design. In the process they used counting of blocks, repeatedly taking a bird's eye view, and the creation of an anchor from which to create the intended design. All of these are strategies that hold relevance to spatial reasoning.

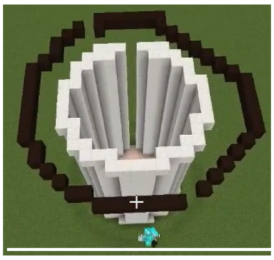

Figure 1. Initial attempt at mushroom rim

Figure 2. Scaffold created by students to anchor mushroom rim

Discussion

The case study includes noticeable instances of intentionally counting, creating physical scaffolds that serve as rulers and grids, and perspective taking, which we assert are relevant to spatial reasoning. Moreover, we see potential alignment between these in-game visual/spatial practices and the visual/spatial anchors that may afford success with the MRT. For example, one strategy for mental rotation is picking a single block within a structure as a reference point, or anchor, and then checking to see if the adjacent portions of the design match the reference object. This bears similarity to the students' process of comparing their in-game design to the images of the design with which we provided them. Accordingly, playing Minecraft may afford opportunities to develop and utilize practices that are beneficial for tasks like MRT.

Conclusion and future work

The overarching motivation for this paper was to examine ways that students exhibit and practice spatial reasoning in Minecraft. We looked across student gameplay data from screen captures and gameplay logs and were able to identify a number of ways that students practice spatial reasoning in Minecraft. We focused our analysis on a single case study that included multiple spatial/visual anchors (a variant of attentional anchors). These anchors took the form of static reference points and scaffolds that would ultimately be removed. The case study also highlights several other spatially relevant practices (e.g., zooming out, or taking a bird's eye view, and counting relative to a specific starting point). Our list of spatial reasoning practices is not meant to be exhaustive, but to, instead, motivate further examination of spatial reasoning in Minecraft and other game-based environments. In future work we will expand and further interrogate these practices through different data collection and analysis strategies. For example, Abrahamson et al., 2016 found significant benefit from studying attentional anchors using eye trackers and think-a-loud protocols. In our forthcoming studies we intend to take a similar approach with the goal of better understanding the ways that the spatial anchors discussed in this paper exist as conscious tools that students are using. We intend to study the development and emergence of spatial reasoning practices over different time scales by conducting a longer-term study with novice Minecraft players.

References

Abrahamson, D., & Sánchez-García, R. (2016). Learning Is Moving in New Ways: The Ecological Dynamics of Mathematics Education. *Journal of the Learning Sciences*. http://doi.org/10.1080/10508406.2016.1143370

Abrahamson, D., Shayan, S., Bakker, A., & Van Der Schaaf, M. (2016). Eye-Tracking Piaget: Capturing the Emergence of Attentional Anchors in the Coordination of Proportional Motor Action. *Human Development*. http://doi.org/10.1159/000443153

Buckley, J., Seery, N., & Canty, D. (2018). A Heuristic Framework of Spatial Ability : a Review and Synthesis of Spatial Factor Literature to Support its Translation into STEM Education, 947–972.

Casey, B. M., Andrews, N., Schindler, H., Kersh, J. E., Samper, A., & Copley, J. (2008). The Development of Spatial Skills Through Interventions Involving Block Building Activities. *Cognition and Instruction*, *26*(3), 269–309. http://doi.org/10.1080/07370000802177177

Feng, J., Spence, I., & Pratt, J. (2007). Playing an Action Video Game Reduces Gender Differences in Spatial Cognition. *Psychological Science*, *18*(10), 850–855. http://doi.org/10.1111/j.1467-9280.2007.01990.x

Glaser, B. G., & Strauss, A. L. (1967). The discovery of grounded theory. *International Journal of Qualitative Methods*, *5*, 1–10. http://doi.org/10.2307/588533

Kulman, R. (2016, July 13). Yes, Video Games Do Improve Spatial Reasoning Skills. Retrieved from https://learningworksforkids.com/2013/08/how-video-games-can-improve-your-childs-spatial-reasoning-skills/

Lane, C., & Yi, S. (2017). Playing With Virtual Blocks: Minecraft as a Learning Environment for Practice and Research. In *Cognitive Development in Digital Contexts*. http://doi.org/10.1016/B978-0-12-809481-5.00007-9

Lane, C., Yi, S., Guerrero, B., & Comins, N. (2017). Minecraft as a Sandbox for STEM Interest Development : Preliminary Results. In 25h International Conference on Computers in Education.

Nebel, S., Schneider, S., & Rey, G. D. (2016). Mining Learning and Crafting Scientific Experiments: A Literature Review on the Use of Minecraft in Education and Research. *Journal of Educational Technology & Society*, *19*(2), 355–366. Retrieved from http://www.jstor.org/stable/jeductechsoci.19.2.355

Ossola, A. (2015, February 6). Teaching in the Age of Minecraft. Retrieved from https://www.theatlantic.com/education/archive/2015/02/teaching-in-the-age-of-minecraft/385231/

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn vandenberg and kuse mental rotations test - different versions and factors that affect performance. *Brain and Cognition*. http://doi.org/10.1006/brcg.1995.1032

Ramey, K. E., & Uttal, D. (2017). Making Sense of Space: Distributed Spatial Sensemaking in a Middle School Summer Engineering Camp. *Journal of the Learning Sciences*, *26*(2), 277–319. http://doi.org/10.1080/10508406.2016.1277226

Sims, V. K., & Mayer, R. E. (2002). Domain specificity of spatial expertise: The case of video game players. Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition, 16(1), 97-115.

Uttal, D., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin*, *139*(2), 352–402. http://doi.org/10.1037/a0028446

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