

Individual Differences and Paired Learning in Virtual Environments

Patricia M. Boechler, Heather M. Gautreau

Abstract—In this research study, postsecondary students completed an information learning task in an avatar-based 3D virtual learning environment. Three factors were of interest in relation to learning; 1) the influence of collaborative vs. independent conditions, 2) the influence of the spatial arrangement of the virtual environment (linear, random and clustered), and 3) the relationship of individual differences such as spatial skill, general computer experience and video game experience to learning. Students completed pretest measures of prior computer experience and prior spatial skill. Following the premeasure administration, students were given instruction to move through the virtual environment and study all the material within 10 information stations. In the collaborative condition, students proceeded in randomly assigned pairs, while in the independent condition they proceeded alone. After this learning phase, all students individually completed a multiple choice test to determine information retention. The overall results indicated that students in pairs did not perform any better or worse than independent students. As far as individual differences, only spatial ability predicted the performance of students. General computer experience and video game experience did not. Taking a closer look at the pairs and spatial ability, comparisons were made on pairs high/matched spatial ability, pairs low/matched spatial ability and pairs that were mismatched on spatial ability. The results showed that both high/matched pairs and mismatched pairs outperformed low/matched pairs. That is, if a pair had even one individual with strong spatial ability they would perform better than pairs with only low spatial ability individuals. This suggests that, in virtual environments, the specific individuals that are paired together are important for performance outcomes. The paper also includes a discussion of trends within the data that have implications for virtual environment education.

Keywords—Avatar-based, virtual environment, paired learning, individual differences.

I. INTRODUCTION

VIRTUAL environments (VEs) are digital, 3D spaces where learners interact with the environment and other learners by controlling the movement and actions of an *avatar*, which then functions as a personal representation of the individual within the digital environment [1].

VEs are more open-ended than video games in that users do not have predetermined scripts or actions associated with their avatars, introducing an unlimited repertoire of potential behaviors and learning opportunities. The digital nature of VEs allows for increased accessibility for learners as geographical barriers are eliminated.

P. M. Boechler and H. M. Gautreau are with the Department of Educational Psychology, University of Alberta, Edmonton, Alberta, Canada (e-mail: patricia.boechler@ualberta.ca, hgautrea@ualberta.ca).

This research is funded by the Social Sciences and Humanities Research Council of Canada.

Besides enhanced accessibility to educational opportunities, VEs embody characteristics that have been strongly linked to improved learner motivation such as, choice, control, challenge, and collaboration [2]. Good et al. [3] report that students' independence, sense of empowerment and responsibility for their own learning is heightened in a VE learning context.

Spatial immersion has also been described as a beneficial affordance of VEs [4] that is related to higher levels of learner attention, engagement and motivation [5]-[7]. Dalgarno and Lee [8] note that spatial immersion can contribute to learning by: a) providing an authentic training experience to support transfer to real life settings, b) providing spatial structure to support conceptualization of information and, c) representing rare, or implausible events that a learner would not experience in real life. Indeed, transfer of spatial and procedural skills from VEs to real world contexts have been documented in the research [9], [10]. Researchers have also demonstrated that navigating a VE requires very similar cognitive abilities to those utilized when completing the same activity in the real world [11]. Although Perani, et al. [12] identified substantial differentiation between learning in real worlds or VEs, they also found that numerous areas of the brain were activated in similar fashion during engagement in both genres.

II. SPATIAL ATTRIBUTES AND LEARNING

Gattis [13] suggests that spatial information acts as representational support for the processing of abstract, non-spatial concepts. That is, the manner in which information is spatially configured suggests semantic relationships within that information. Spatial schemas help to structure memory, communication and reasoning, suggesting that spatial layouts of information can impact a learner's conceptual development of the material to be learned. The overall notion is that spatial information functions as a depictive structure which can represent distance, relations between concepts or semantic differences/similarities. Research has demonstrated that spatial ability is linked to academic performance in areas such as chemistry and mathematics [14]-[16].

III. INDIVIDUAL DIFFERENCES

Given that spatial attributes are an important aspect of VEs, and that spatial schemas potentially contribute to learning, it would follow that an individual's spatial ability would be relevant to learning within such environments. Prior research supports this as Van Oostendorp and Karanamb [17] found that navigation support in a VE enhanced performance for low spatial ability students more than for those with high spatial

ability. When spatially-based tasks are executed within VEs, research shows that there is a higher degree of variability in participants' performance than in real world spatial tasks [9]. Boechler et al. [18] found that learners with higher spatial ability retained more information in a VE task than learners with low spatial ability. Individual differences in spatial ability appear to influence performance in VEs.

Aspects of prior computer experience have also been reported as related to learning outcomes in VEs [18].

IV. SOCIAL CONTEXT AND LEARNING

From the psychological literature, numerous learning and psychological theories argue that social interaction is essential for the construction of meaning and understanding of information and objects within the environment. For instance, Bandura's socio-cognitive theory, versions of Vygotsky's Sociocultural Theory (such as the Cognitive Apprenticeship Model and Social Constructivism) all promote social interaction as a necessary condition for learning [19], [20]. All of these theories have had profound effects on educational practice.

Jorczak's [21] Collaborative Information Processing Theory provides a theoretical basis for understanding learning principles associated with computer-mediated social interaction, specifically, the relationship between collaborative peer-to-peer processes and individual cognitive processes. "The individual processes of externalization and internalization describe how information flows to and from individual cognitive systems and a shared information pool of symbolic information (e.g., discourse, mutually-created graphics and documents). Externalized information can diverge and converge (represent different or similar knowledge) as group members try to meet group goals established by a collaborative learning task." [21]. The sharing of divergent information in peer-to-peer interactions heightens conceptual conflict for the individual, which is the primary benefit of collaborative learning over individualistic learning. In response, students use social processes (e.g., clarification and negotiation) to make information more meaningful to others, and to reduce their own conceptual disparities.

For VEs in particular, researchers have studied the value of the collaborative learning opportunities they provide [22]-[24]. For example, a number of studies have been undertaken on the benefits of using virtual environments as a setting within which to engage in communication [25]. In their meta-analysis on the use of virtual environments for educational purposes, Reisoglu, et al. [26] found that collaboration and communication were two of the most highly prized skill sets when it came to the design of learning activities.

V. SPATIAL AND SOCIAL PROCESSES TOGETHER

Proxemics is the study of how peoples' use of space reflects and conveys social relationships [27]. Behavioral evidence shows that, when manipulating their avatars in VEs, people adhere to real-world norms of interpersonal space, even though there are no physical consequences to "bumping into"

another avatar [28].

In real world studies, Dodson and Shimamura [29] found that settings which contain human faces and voices amplify the association for context and help later recall of previously learned material. A meta-analysis conducted by Smith and Vela [30] indicated that recall is optimal when the same people present in the encoding phase are also present during retrieval of information.

Finally, recent neuropsychological research pairs spatial and social processing together as having shared neural mechanisms. "A growing body of research suggests that brain mechanisms supporting sophisticated social abilities may derive from low-level processes such as spatial tracking, predictive encoding, and attention shifting" [31]. Abraham et al. [32] found that the temporoparietal junction is activated when subjects think about others' false beliefs and positions in space, suggesting that processes of spatial and social cognition recruit similar neural systems.

As a preliminary investigation of the elements described in the literature review above, we created a very simple VE task using Unreal Engine with few visual details and limited communication options. Our general research questions were: 1) Does paired learning result in improved learning outcomes over independent learning? And, 2) What individual traits and experiences are associated with better learning outcomes?

VI. METHODS

A. Participants

A total of 173 first year education students were recruited through the Educational Psychology Research Participant Pool in the Faculty of Education at the University of Alberta.

B. Premeasures

All participants completed several premeasures before the VE learning task. Social media experience (SME), video game experience (VGE) and awareness of software titles were measured (SRT) using the Computer Experience Questionnaire (CEQ) [33].

Two measures of spatial ability were collected; demonstrated spatial skill and perceived spatial skill. Kozhevnikov and Hegarty's [34] Spatial Orientation Test (SOT) was administered to measure demonstrated spatial skill. This test requires participants to indicate in which location an object would appear in an array of objects when the individual's location is changed within that array. As an example, a participant would be presented with a configuration such as the one in Fig. 1 and would be given the instruction to "Imagine you are standing at the **car** and facing the **traffic light**. Point to the **stop sign**" [35].

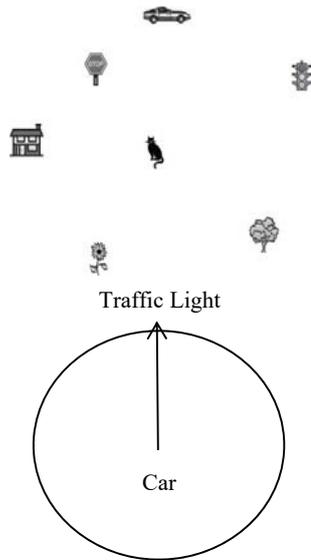
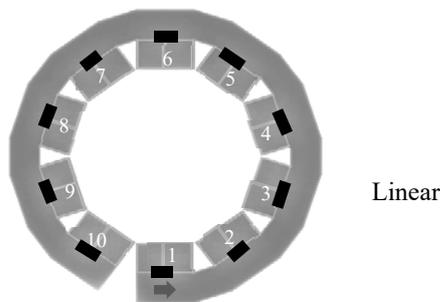
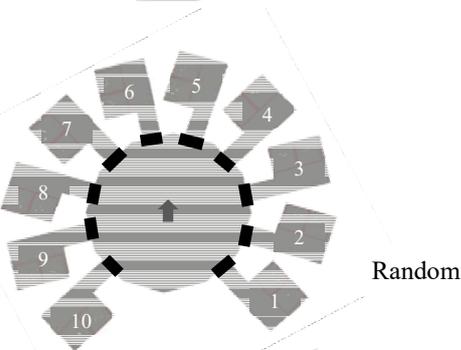


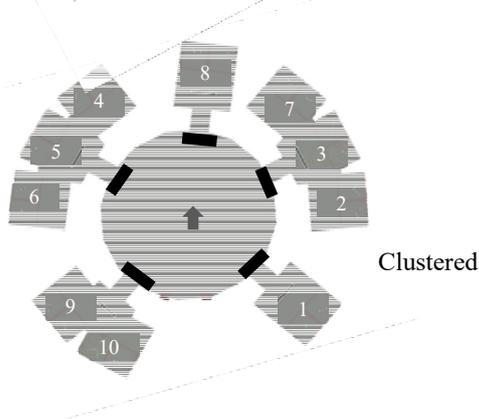
Fig. 1 Sample of Spatial Orientation Test (SOT) [35]



Linear



Random



Clustered

Fig. 2 The Configuration of the Linear, Random and Clustered Virtual Learning Environments [8]

C. Procedures

After the completion of the premeasures, students logged into the VE and were assigned to one of the three spatial conditions and either the independent condition or the paired condition. Paired learners also had access to a text chat to communicate with their partner if they chose to do so. The independent learners received instructions to view all the information within the VE. The paired learners' received instructions to view all the information within the VE and were given information about how to communicate with their partner. At the end of the learning phase, all learners were tested individually with a 10-item multiple choice test on the material they had just viewed.



Fig. 3 Screenshot of Linear Condition



Fig. 4 Screenshot of Clustered Condition

VII. RESULTS

Participants were randomly assigned to either a single or a paired condition before completing a virtual environment learning task. Learning outcomes were measured by participants' scores on a multiple-choice test following their participation in the VE task. A one-way between-subjects ANOVA was conducted to compare the learning outcomes of participants who completed the task individually, versus those in the paired condition.

The results of the ANOVA were not significant at the $p < 0.05$ level [$F(1,172) = 1.199, p = 0.275$], indicating that participants performed equally well in both the individual and paired conditions.

A standard multiple regression analysis was performed to assess the ability of individual differences to predict the variation in participants' learning outcomes. The results of the regression analysis indicated that individual differences

accounted for 81.5% of the variability in participant scores [$R^2 = 0.815$, $F(5,168) = 148.109$, $p = 0.000$]. Participant scores on a measure of demonstrated spatial ability were the only participant variable to predict performance on learning outcomes ($\beta = 0.803$, $p = 0.000$).

Video game experience ($\beta = -0.007$, $p = 0.639$), social media experience ($\beta = -0.018$, $p = 0.339$), general computer experience ($\beta = 0.012$, $p = 0.740$), and self-perception of spatial capacity ($\beta = -0.004$, $p = 0.328$) did not predict participant outcomes.

To further understand the role of spatial ability, participants within each randomly formulated pair were compared with each other to determine if they were matched or mismatched with regard to their demonstrated spatial ability. If a pair was matched, it was further determined whether they were matched with high scores, or matched with low scores. Descriptives for the three categories of paired spatial ability are provided in Table I.

TABLE I
 RANGE, MEAN AND STANDARD DEVIATION OF SOT SCORES WITHIN PAIRS

Pairs	n	Score Range	Mean Score	Standard Deviation
Mismatched Scores	45	0 – 9	5.20	2.007
Matched-Low Scores	49	1 – 5	3.47	1.157
Matched-High Scores	8	6 – 9	6.63	1.061

One-way between-subjects ANOVAs were conducted to compare the effect on learning outcomes of participants' pre-measured spatial orientation skills. There was a significant effect of mismatched ability on test scores at the $p < 0.05$ level [$F(1, 100) = 13.123$, $p = 0.000$]. There was also a significant effect of matched-low ability on test scores at the $p < 0.05$ level [$F(1, 100) = 36.640$, $p = 0.000$]. In addition, there was a significant effect of high matched ability on multiple-choice test scores at the $p < .05$ level [$F(1, 100) = 12.495$, $p = 0.001$]. In addition, an analysis of between-subjects effects was run on the three types of pairs. There was a significant effect of matchedness on test scores at the $p < 0.05$ level [$F(2, 99) = 21.879$, $p = 0.000$]. A graphic comparison of the mean test scores for each category of paired spatial ability is provided in Fig. 5.

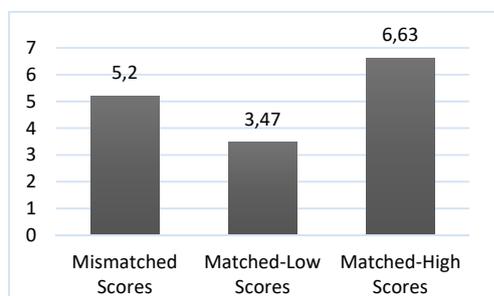


Fig. 5 Spatial Ability Scores within Pairs

A post hoc test was calculated to compare each of the types of pairs to every other type. The results of a Tukey test showed a significant difference ($p = 0.000$) between the test

scores of mismatched ($M = 5.20$, $SD = 2.007$) and matched-low pairs ($M = 3.47$, $SD = 1.157$) pairs, as well as a significant difference ($p = 0.000$) between the scores of matched-high pairs ($M = 6.63$, $SD = 1.061$) and matched-low pairs. However, the results of the Tukey test revealed no significant difference ($p = 0.055$) between the test scores of mismatched pairs and matched-high pairs.

The results of this study suggest that when students are working in pairs during a virtual environment learning task, matching students according to their spatial ability may impact their learning outcomes. When two students with high spatial ability were paired together ("matched-high"), they were the most likely to demonstrate strong learning outcomes. Conversely, when two students with low spatial ability were paired ("matched-low"), they were the least likely to achieve positive learning outcomes. However, when a student with low spatial ability was paired with a student whose spatial ability was high, the "mismatched" pair achieved a score that was significantly higher than the matched-low students, yet was not significantly lower than the matched-high students.

These results suggest that when pairs of students are completing a virtual environment task, including at least one individual in each pair who has a strong capacity for spatial navigation is likely to positively impact the learning outcomes for both students.

VIII. DISCUSSION

In this study we investigated whether there were differences in participants' learning when they completed a VE task alone or with another person. Our overall analyses showed that learning was not enhanced across either condition. Independent and paired learners performed equally. As a preliminary investigation of paired vs. independent learning, we designed the VE task to be very simple with only one channel for communication (text chat) for the paired participants. Although paired learners did use the chat feature, they did not use it enough for us to conclude if the content of the chat may have influenced performance.

We also tested three spatial conditions and although our prior results [18] indicated a clustered configuration of the information supported learning more than linear or random, there was no difference within this sample.

Prior research on learning in VEs has indicated that spatial ability plays a role in improved performance on learning measures. This was the case in this study as well with higher spatial ability participants retaining more information than lower spatial ability participants. This occurred for both independent learners and paired learners. None of the other individual difference measures employed in this study (perceived spatial skill, video game and social media experience and general awareness of software applications) were related to better outcomes. It is somewhat surprising, perhaps, that video game experience was not related to increased learning; however, the VEs used in this study were very simple with no extraneous visual elements. It is possible that in more visually complex VEs, video game experience may be more relevant.

IX. CONCLUSION

Even in a very simplified version of a VE, we found that the spatial ability of the learner was linked to better retention of the material they viewed. To further understand the role of social learning in VEs, we are currently developing a more complex VE with a more demanding learning task accompanied by increased opportunities for communication between learners.

REFERENCES

- [1] R. Martenstyaro, and Y. Rosmansyah, "A framework for designing survey training based on 3D virtual learning environment using SLOODLE," In: *2015 International Conference on Information Technology Systems and Innovation (ICITSI)*, 2015.
- [2] F. Gao, J. J. Noh, and M. J. Koehler, "Comparing Role-playing Activities in Second Life and Face-to-Face Environments," *Journal of Interactive Learning Research*, vol. 20, pp. 423-443. Chesapeake, VA: AACE, 2009.
- [3] J. Good, K. Howland, and L. Thackray, "Problem-based learning spanning real and virtual worlds: A case study in Second Life," *ALT-J, Research in Learning Technology*, vol. 16, pp. 163-172, 2008.
- [4] J.J. Gibson, "*The ecological approach to perception*. Hillsdale, NJ: Lawrence Erlbaum Associates, 1986.
- [5] B. Cho, K. Jeonghun, J. Dong Pyo, K. Saebyul, L. Yong Hee, "The effect of virtual reality cognitive training for attention enhancement," *Cyberpsychology & Behavior*, vol. 5, 129-13, 2002.
- [6] H.G. Hoffman, "Virtual-reality therapy," *Scientific American*, vol. 291, pp. 58-65, 2004.
- [7] N. Yee, "Motivations for play in on-line games," *Cyberpsychology and Behavior*, vol. 9, pp. 772-775, 2006.
- [8] B. Dalgarno, and M.J.W Lee, "What are the learning affordances of 3-D virtual environments?," *British Educational Technology*, vol. 41, pp. 10-32, 2010.
- [9] D. Waller, D. Knapp, and E. Hunt, "Spatial representations of virtual mazes: The role of visual fidelity and individual differences," *Human Factor*, vol. 43, pp. 147-158, 2001.
- [10] F. D. Rose, F. D., E. A. Attree, B. M. Brooks, D. M. Parslow, D. M., P. R. Penn, and N. M. Ambihapahan, "Training in virtual environments: transfer to real world tasks and equivalence to real task training," *Ergonomics*, vol. 43, pp. 494-511, 2000.
- [11] M. Allahyar, and E. Hunt, "The assessment of spatial orientation using virtual reality techniques," *International Journal of Testing*, vol. 3, pp. 263-275, 2003.
- [12] D. Perani, F. Fazio, N. A. Borghese, M. Tettamanti, S. Ferrari, J. Decety, and M.C. Gilardi, "Different brain correlates for watching real and virtual hand actions," *NeuroImage*, vol. 14, pp. 749-758, 2001.
- [13] M. Gattis, "Mapping relational structure in spatial reasoning," *Cognitive Science*, vol. 28, pp. 589-610, 2004.
- [14] M. Kytälä, "Visuospatial working memory in adolescents with poor performance in mathematics: variation depending on reading skills," *Educational Psychology: An International Journal of Experimental Educational Psychology*, vol. 28, pp. 273-289, 2008.
- [15] Z. Merchant, E. T. Goetz, W. Keeney-Kennicutt, O. Kwoka, L. Cifuentes, and T. J. Davis, "The learner characteristics, features of desktop 3D virtual reality environments, and college chemistry instruction: A structural equation modeling analysis," *Computers & Education*, vol. 59, pp. 551-568, 2012.
- [16] W. Hwang, and S. Hu, "Analysis of peer learning behaviors using multiple representations in virtual reality and their impacts on geometry problem-solving," *Computers & Education*, vol. 62, 308-319, 2013.
- [17] H. van Oostendorp, and S. Karanam, "Using a Cognitive Model of Web-Navigation to Generate Support for 3D Virtual Navigation," *Procedia Computer Science*, vol. 15, pp. 283-284, 2012.
- [18] P. Boechler, H. Gautreau, E. deJong, and P. Sterling, "Towards a Psychological Model for Learning in Avatar-based Virtual Environments: How Important is Spatial Processing?," In T. Bastiaens, J. Van Braak, M. Brown, L. Cantoni, M. Castro, R. Christensen, G. Davidson-Shivers, K. DePryck, M. Ebner, M. Fominykh, C. Fulford, S. Hatzipanagos, G. Knezek, K. Kreijns, G. Marks, E. Sointu, E. Korsgaard Sorensen, J. Viteli, J. Voogt, P. Weber, E. Weippl & O. Zawacki-Richter (Eds.), *Proceedings of EdMedia: World Conference on Educational Media and Technology*, pp. 2075-2083, 2018, Amsterdam, Netherlands: Association for the Advancement of Computing in Education (AACE).
- [19] D. H. Shunk, *Learning theories: An educational perspective* (3rd ed). Upper Saddle River, NJ: Prentice-Hall, 2000.
- [20] A. S. Palincsar, A. S. (1998). Social constructivist perspectives on teaching and learning," *Annual Review of Psychology*, vol. 49, pp. 345-375, 1998.
- [21] R. L. Jorczak, "An information processing perspective on divergence and convergence in collaborative learning," *Computer-Supported Collaborative Learning*, vol. 6, pp. 207-221, 2011.
- [22] S. Bronack, R. Riedl, and J. Tashner, "Learning in the zone: A social constructivist framework for distance education in a 3-dimensional virtual world," *Interactive Learning Environments*, vol. 14, pp. 219-232, 2006.
- [23] V. Chang, C. Gütl, S. Kopeinik & R. Williams, "Evaluation of collaborative learning settings in 3D virtual worlds," *International Journal of Emerging Technologies in Learning*, vol.3, pp. 6-17, 2009.
- [24] R. Hanewald, "Learners and collaborative learning in virtual worlds," *Turkish Online Journal of Distance Education*, vol. 14, pp. 233-247, 2013.
- [25] K. F. Hew & W. S. Cheung, "Use of three-dimensional (3-D) immersive virtual worlds in K-12 and higher education settings: A review of the research," *British Journal of Educational Technology*, vol. 41, pp. 33-55, 2010.
- [26] I. Reisoglu, B. Topu, R. Yilmaz, T. K. Yilmaz, and Y. Goktas, "3D virtual learning environments in education: a meta-review," *Asia Pacific Education Review*, vol. 18, pp. 81-100, 2017.
- [27] E. T Hall, *The Hidden Dimension*. Anchor Books, 1996.
- [28] J. N. Bailensen, J. Blascovich, A. C. Beall, and J. M. Loomis, "Interpersonal Distance in Immersive Virtual Environments," *Personality and Social Psychology Bulletin*, vol. 29, 7, pp. 819-833, 2003.
- [29] C. S. Dodson & A. P. Shimamura, "Differential effects of cue dependency on item and source memory," *Journal of Experimental Psychology: Learning, Memory, and Cognition*, vol. 26, pp. 1023-1044, 2000.
- [30] S. M. Smith & E. Vela, "Environmental context-dependent memory: A review and metaanalysis," *Psychonomic Bulletin & Review*, vol. 8, pp. 203-220, 2001.
- [31] Y. Sun & H. Wang, "Insight into others' minds: spatio-temporal representations by intrinsic frame of reference," *Frontiers in Human Neuroscience*, vol.8, pp. 58, 2014.
- [32] A. Abraham, M. Werning, H. Rakoczy, D. Y. von Cramon & R. I. Schubotz, "Minds, persons, and space: an fMRI investigation into the relational complexity of higher-order intentionality," *Conscious Cognition*, vol. 17, pp. 438-450, 2008.
- [33] P. Boechler, K. Dragon & E. Wasniewski, "Relationships between Digital Literacy and Print Literacy: Predictors of Successful On-line Search," In P. Resta (Ed.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2012*, pp. 1755-1758, 2012.
- [34] M. Kozhevnikov & M. Hegarty, "A dissociation between object manipulation spatial ability and spatial orientation ability," *Memory & Cognition*, vol. 29, pp. 745-756, 2001.
- [35] M. Hegarty, A. E. Richardson, D. R. Montello, K. Lovelace & I. Subbiah, "Development of a self-report measure of environmental spatial ability," *Intelligence*, vol. 30, pp. 425-47, 2002.