# Gamification for spatial literacy: The use of a desktop application to foster map-based competencies

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**Abstract**

Spatial literacy in education not only possesses the potentials of individual success but also fosters the transdisciplinary importance of spatial information use in society. Particular spatial competencies in domains such as geography are discussed as means to foster spatial learning and spatial thinking. At present, performances in spatial tasks vary largely among individuals. These variations may be based on ability and/or on acquired competence. We designed a gamified application intending to foster spatial competencies. This application is called Ori-Gami (Orientation Gaming) which runs on desktop computers. Tasks involve map-based orientation and navigation with three different types of route instructions: egocentric, allocentric or landmark-based. The present study examines performance in a spatial task following different route instruction considering spatial abilities (spatial encoding, perspective taking, and mental rotation) that may play a role. Results suggest that egocentric route instructions involving corrections of misalignment decreases accuracy compared to the other instruction types. Therefore, the game could be optimized particularly in supporting and/or fostering individual's competence for such corrections. Spatial abilities were not found related to performance in this study, with one notable exception. Mental rotation speed was substantially related to accuracy in the egocentric instruction condition with required corrections of misalignment.
*Keywords*: gamification, spatial learning, spatial competency, spatial ability, education

## 1 Introduction

Spatial literacy in curricula not only possesses the potentials of individual success but also fosters the importance of spatial information use in society. It is important to point learners early on to the transdisciplinary power of spatial information use and spatial thinking in order to support the development of spatial skills and competences. The importance of spatial literacy in curricula has been pointed out by Goodchild [1] regarding the transdisciplinary competence of spatial, mathematical, and linguistic literacy in all subjects: from STEM [1], to social sciences and arts. The National Research Council (NRC) report "Learning to think spatially" shares the same view and suggests solutions for geographic information systems (GIS) as a support system to think spatially [2]. Approaches using minimal GIS for all grade levels at school, when particular spatial concepts were incidentally used, follow this direction in several studies [3-5].

We aim to develop tools, which are not based on existing GIS but adapting an interdisciplinary perspective instead, to support spatial thinking by fostering skills for orientation, wayfinding, and map understanding. We integrate these skills in a tool that adapts concepts of game-based learning. In this paper we present the desktop version of our app "Ori-Gami " (Orientation Gaming), which is a game to enhance students' map understanding, orientation, and wayfinding skills which compose spatial competency development in most curricula [6, 7]. The application developed within this project follows the curricular requirements ("spatial orientation") and practical requirements, since schools do not concentrate on outdoor activities for classes of geography [8, p. 74] where spatial competencies can be fostered. In the present study, a map-based route-following task (a variant of the game) is examined with respect to the spatial perspective of verbal route instructions. Moreover, the relation between game performance and spatial abilities is investigated.

Since maps are typically studied with the particular north-on-top orientation, judgments of relative directions from memory are more difficult if they require reorientation, i.e., imagining another position and orientation than the orientation from which the representation has been studied. Mental representations of spatial configurations are thus thought to be orientation dependent [9-13]. The orientation specificity effect is also termed alignment effect. Alignment effects are considered robust [10, 14]. They occur both with large and small layouts [11]. The effect can be experienced in everyday spatial activities such as navigation. For instance, misaligned you-are-here maps impede orientation in a real environment [15-17]. This suggests that alignment plays a role in map reading when planning a route and not only for retrieval from memory. In the present study, naturalistic maps were utilized in different route instruction conditions. It was expected that an instruction that describes the route from an egocentric point of view would cause alignment problems when participants try to follow the route.

## 2 Related work

Education systems all over the world start integrating the use of spatial technologies in their curricula to foster competences like spatial orientation – mostly in the geography context, but also interdisciplinary in and beyond K-12 and undergraduate studies [18]. However, fundamental definitions on spatial thinking and interconnection of concepts in the related disciplines and communities still are not established.

[1] short for science, technology, engineering, and mathematics

Especially there is a lack of organization, concrete vocabularies and conceptualizations in the domain of spatial learning in connection or in relation to spatial information. Established test methods for measuring these competences are still missing. While spatial competence is a central aspect of human adaption [6] we have to face new developments in technology and education by strengthening these competencies.

Mohler [19] points out that studies have started to address the effect of technology on the measure and improvement of spatial abilities. This implies that although technology has been used in the tests of spatial ability, the role of technology is supplemental. How technology can be used in a more central role such as facilitating the enhancement of spatial competency instead of the mere role of measuring seems to be the necessary following step. For example in a recent study among students of dental educations, Hegarty and colleagues [20] found that ability of spatial visualization is correlated with academic performance. The aim was investigating how spatial abilities were enhanced by dental education. The next logical question is if any test or mechanism associated with spatial ability could be used to enhance the spatial competence in specific field. To approach this ultimate goal, we started investigating the influences of several design variables of the spatial learning tool on particular aspects of spatial competencies. Moreover, we intend to examine the association of spatial abilities with these spatial competencies. Results of this study will shed light on designing tools with the purpose of enhancing spatial competencies, instead of testing.

In short, our research aims at supporting spatial competency development through spatial technologies. While most research initiatives make use of using existing GISs to teach and support spatial thinking processes, we develop our own applications designed for fostering particular competencies (orientation competency with maps in this study) of children and young adults at a particular age range.

## 3 Development of Ori-Gami

Spatial orientation is one of the key competencies in most curricula, mostly in geography or social studies classes. In the German educational standards in geography [6] spatial orientation is one of six key competencies to be acquired in geography education. Map understanding and wayfinding in real space are subcompetencies and both consist of concepts as describing locations and describing routes. The use of supporting technologies as GIS in map competence or GPS in wayfinding is a competence itself. The Ori-Gami app fosters spatial orientation and underlying competencies including map understanding, orientation, and navigation in a game-based learning style.

### 3.1 The App

Ori-Gami is an orientation gaming app for browsers or tablets. Depending on the platform it can be used in mobile with GPS or stationary condition. It consists of a simple base map and displayed route instructions of varying complexity, for example using egocentric directions, cardinal directions, landmarks and distances. The instructions can be provided and edited by the teacher or the game leader in an online editor.

The editor itself allows adding waypoints to the map and describing the verbal instructions for reaching each waypoint. Optionally hints for each waypoint may be added. Saving the route generates a route code, which can be distributed to the players. In the game the user can load a route and either click on the decision points described in the verbal instructions in the browser version or walk along the instructed path with the device in the tablet version of the app.

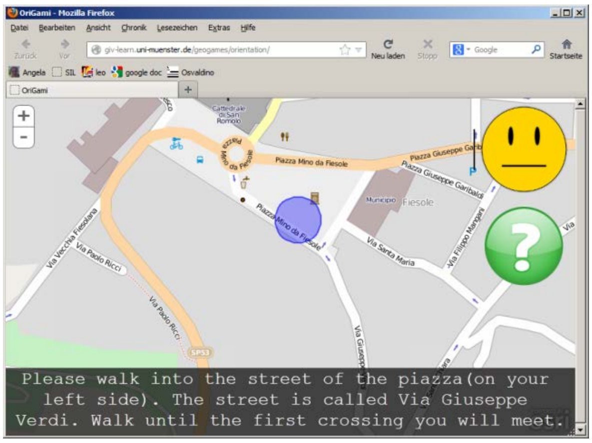



Fig. 1. Screenshot of the Ori-Gami App in a browser that ran on a desktop computer.

Feedback, hints and game elements allow the user to orientate and find reference points in the map and in the real world. The blue circle in the map indicates the current position located by the device or selected by the user by clicking on the map. The smiley provides feedback on the current position: It changes color and friendliness (smile or scowl) to give intuitive hints whether the player is moving or clicking into the direction of the next waypoint. Each time the player reaches a waypoint (in the browser version there is a tolerance distance for clicking, depending on the zoom level), the app signals this by playing a sound and visually via a happy smiley and a text message. The next wayfinding instructions are automatically displayed at the bottom of the screen. A trumpet sound and a text at the end of a route gives the user feedback, that she has reached the goal.

The interface design is kept extremely simple, by choosing the map as main element, covering the whole screen. There is a half transparent area in the bottom for the route instructions and the visual feedback in form of the smiley as game elements. If the game leader has entered hints in the editor, a help button with a big question mark is made available in the game as the only button of the whole interface.

The simplicity of the interface, the possibility of editing routes all over the world, and the fact that verbal instructions and hints may be added in every language allows international and intercultural use of this system. As OpenStreetMap is available as basemap, experienced teachers or game leaders are even able to edit the base-map via OpenStreetMap editors such as Potlatch or JOSM to add specific landmarks that would support orientation.

## 3.2 The App as Measuring Tool

The app has several possibilities to record the user interactions for analysis in terms of usability or learning. The tablet version records the GPS-Track, the touch coordinates and gestures, the zoom level of the map and the time required for each route. For optional thinking-aloud tests it can also record sound and allow further usability analysis. The browser version records the time from loading the route to successfully finishing it by reaching the goal, each click coordinate, the distance to the actual waypoint and the zoom level of the map at each click. These designs allow the use of the app and its recorded data as a variable in tests on spatial learning.

Spatial abilities – i.e., storing and manipulating mental visual-spatial representations (see [21] for a review) – play an important role for learning from external visualizations. Visual-spatial abilities were found to be an important predictor of spatial configurational learning in previous studies if the to-be-learned environment was actively or passively studied from visual media [22-24]. Walking an unknown route through a real, unknown building was related to the ability to encode visual-spatial information as measured with the hidden patterns test [25]. The route was studied from different visualizations shown on a tablet computer (maps, pictures of decision points, animation of the route through a virtual building) at the entrance of the building. It is thus expected that reading a map for following a route would be associated with spatial abilities, i.e., participants with lower abilities would make more errors in a route-following task.

The present study investigated performance in the map-based learning game in different route instruction conditions. Participants were asked to follow a route by clicking waypoints that were verbally described. Route instruction conditions differed mainly with respect to the spatial perspective adopted (allocentric route instructions, egocentric route instructions, landmark-based route instructions). Map reading for following the route required search processes and corrections for alignment particularly in the egocentric route condition. The egocentric route condition was therefor expected to be more difficult because mental processes of perspective taking were inevitable. These processes may depend on spatial abilities and on acquired competencies. The present study aimed at clarifying the role of spatial abilities in the map-based route-following game in the different route instruction conditions.

# 4 Method

Twenty-six participants took part in the experiment (22 were female). They were teacher and psychology students at one of the authors' university. The average age was 21.6 (*SD* = 3.5). Participants received course credit for participation.

## 4.1 Materials

**Spatial Ability Tests.** The hidden patterns test [26] measures encoding and recognizing a simple figure which is embedded in a more complex line drawing (Fig. 2). Two-hundred items were shown on four pages. Participants answered by marking answer boxes below the items. The overall processing time was restricted to three minutes. In the scoring procedure, the number of incorrectly marked answers was subtracted from the number of correctly marked ones. A reliability of .91 is reported for this test [26, p. 11].

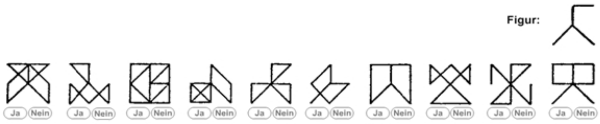


Fig. 2. Sample item of the hidden patterns test

In the perspective taking test [27, 28], participants are asked to make directional judgments based on a map which shows a spatial configuration of seven objects (Fig. 3). Participants imagine themselves standing at a particular position (e.g., at the traffic light), facing a particular second location (e.g., the stop sign), and pointing to another location (e.g., the flower). The directional judgment is indicated by a position to be marked on the answer circle. The map is visible during answering. The test requires estimating directions from imagined positions with orientations that deviate from the "upright/north" orientation of the map typically more than 90 degrees. Participants process twelve items, all utilizing the same map. The score of the participant is the average angular error calculated from the items that the participant attempted to solve within the given time of five minutes. Reliability estimates between .79 and .85 (Cronbach's alpha statistic) are reported for this test [27].

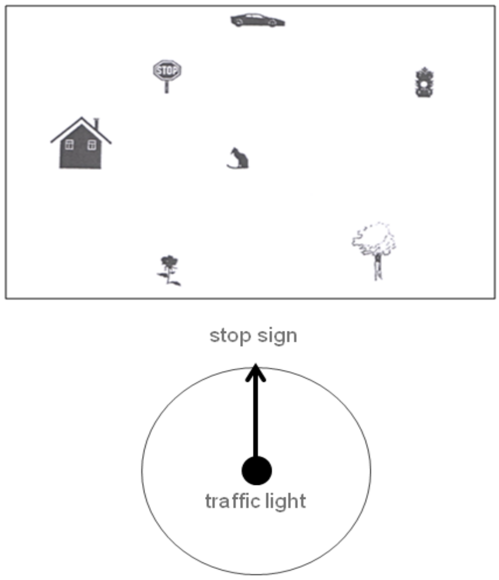
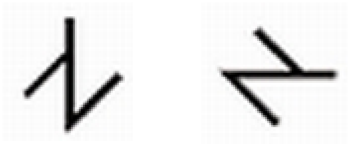


Fig. 3. Perspective taking test map. The answer is marked on the circle.

A computer-based test on mental rotation ability including reaction time measures was created after a description provided by [29], using PMA symbols [30]. For each item, an original symbol and a comparison symbol was shown on the screen (Fig. 4). The comparison symbol was rotated with an angular disparity of 0º, 45º, 90º, and 180º. The comparison symbol either was identical to the symbol on the left, or it was mirrored. Participants were asked to determine as quickly as possible whether the two symbols were identical or not. The test included sixty items. Reaction times as well as accuracy (number of wrong answers) were measured. Jansen-Osmann and Heil [29] estimated reliability with the Odd-Even method and reported r = .91 for the reliability of this test.



original symbol comparison symbol

Fig. 4. Example symbols presented on Chronometric mental rotation test.

**Materials: Route Instructions.** We selected three routes in three different urban locations in Germany for the route-following task. The three routes are comparable in complexity: ten instructions had to be executed to reach the goal. The routes contain eight turns at waypoints and in-between waypoints. For each route we created landmark-based, egocentric and allocentric route instructions (Table 1).

Table 1. Examples (translated from German) for an initial instruction at the start point and for an instruction at a waypoint in all three conditions (landmark, egocentric, allocentric).

| | Landmark | Egocentric | Allocentric |
|---|---|---|---|
| Initial instruction for orientation | On your right you see the Sacred Heart Church. On your left you see the Old Postman Pub. Go to the next junction. | You are looking in the direction of “Cologne Street”. Go straight until you reach the next junction. | Go south until you reach the next junction. |
| Instruction at a waypoint | Turn and go to the Art house. | Turn right and walk along the street until you reach the second junction | Turn north and walk until you reach the second junction. |

The landmark-based route instructions used solely landmarks to give directions. All landmarks were visible on the highest and second-highest zoom level. They were represented either via a symbol, a label, the footprint of the landmark, or a combination. Egocentric instructions used only egocentric turn directions. Only for the initial orientation at the start point a landmark was used. The allocentric instructions used only allocentric turn directions. All three route instructions used the terms junction, round-about, and footpath to refer to special features of the street network on the map.

### 4.2 Procedure

Participants were administered the spatial ability tests first (hidden patterns test, perspective taking test, mental rotation test). Subsequently, participants completed three route-following tasks corresponding to the three instruction conditions. All participants completed the route-following tasks in all of the three instruction conditions (allocentric, egocentric and landmark-based route instruction condition). The order of the route instruction conditions was balanced among participants. The three different route instruction conditions were combined with three different actual routes based on three different city maps such that each participant received the three route instructions based on different actual routes. Each actual route was equally often presented with a particular route instruction. Participants were tested in small groups of 2-5 in a multimedia laboratory with separate work spaces. The experiment lasted about 40 minutes.

## 5 Results and Discussion

Due to a technical error, the data of two participants were lost for the mental rotation test and the measurement of the landmark-based route instruction condition. The data set was screened for outliers which were defined as values above or below 2.5 standard deviations from the mean (*M* and *SD* calculated with original data). In both the hidden patterns test score and the perspective taking test average angular error, there was one value found that exceeded 2.5 *SD*. This value was replaced by the mean of the variable. Some outliers were found in the accuracy (number of errors) in the route instruction conditions. In the allocentric condition, two values indicated an extremely high number of errors, in the egocentric condition, four numbers of errors were extremely high, and in the landmark condition, one value indicated a high number of errors. Errors represent clicks on the map that are placed outside a predefined area around the correct intersection or location. A closer inspection of these clicks revealed that these participants obviously clicked on the complete route (i.e., they simulated walking along the streets by clicking “along” the streets) and not only on the waypoints.

Moreover, this behavior could only be observed if the respective route instruction condition was the first condition that the participant received. Thus, the incorrect clicks were attributed to a misunderstanding of the experimental instruction rather than to a particular difficulty or incompetence of the participant. Therefore, the respective values were replaced by the mean of the respective variable. If a participant made an extremely high number of errors, then the time needed to complete the condition increased accordingly. Therefore, also times were corrected (replaced by the mean of the respective variable) for participants for whom the number of errors had been replaced.

An analysis of variance with route instruction condition as within-factor revealed a marginally significant effect of route instruction condition on the number of errors, $F(2,46) = 3.16$, $p = .052$, partial eta square = .12. In contrast, the time needed to complete the task did not differ between route instruction conditions, $F(2,46) = 1.42$, ns, partial eta square = .06, although errors were related to time (correlations between completion times and accuracy were $r = .56$, $p < .01$ in the landmark condition, $r = .77$, $p < .01$, in the allocentric condition, and $r = .79$, $p < .01$, in the egocentric condition).

Table 3 shows correlations between the spatial abilities tests and the accuracy measures in the three route instruction conditions. Whereas accuracy in the allocentric condition was found to be substantially related to accuracy in the egocentric condition, accuracy in the landmark condition was neither related to accuracy in the allocentric nor to accuracy in the egocentric condition. The hidden patterns test score correlated negatively with the mental rotation reaction time, which implies that, the better participants scored in the hidden pattern test, the shorter was the reaction time. Furthermore, mental rotation reaction time was correlated with accuracy in the egocentric condition. No other correlations were found between spatial abilities and accuracy in any of the route instruction conditions.

Table 2. Bivariate correlations between measures (spatial abilities tests and accuracy in the route instruction conditions)

| | HP | PT | MR | ACC-ALLO | ACC-EGO |
|---|---|---|---|---|---|
| Perspective taking test average angular error (PT) | -.15 | | | | |
| Mental rotation test average reaction time (MR) | -.51* | -.26 | | | |
| Accuracy in the allocentric condition (ACC-ALLO) | -.25 | -.00 | .11 | | |
| Accuracy in the egocentric condition (ACC-EGO) | -.20 | -.05 | .42* | .49* | |
| Accuracy in the landmark-based condition (ACC-LANDM) | .00 | .29 | -.00 | .28 | .16 |

Note. $*p < .05$

These results suggest that the egocentric route instruction condition was more difficult than the allocentric and the landmark-based instruction conditions. However, it is conceivable that particularly the egocentric route instructions are utilized for communicating and planning a route with a map. Thus, instructions for routes in combinations with maps can cause predictable challenges depending on the spatial perspective chosen in the route description.

In contrast to expectations, neither the hidden patterns test nor the perspective taking test predicted accuracy in any route instruction condition. Only the mental rotation test predicted the number of errors, but only in the egocentric route instruction condition. This pattern suggests that mental rotation ability played a critical role only when misalignment had to be corrected for understanding the verbal route instructions. Performance in the allocentric condition and in the landmark-based condition was presumably based on map reading competencies skills not captured by the spatial ability tests. For instance, the allocentric route condition might have required routine knowledge of cardinal directions to follow the route on the map.

## 6 Conclusion

Humans differ in their spatial problem solving performance such as completing navigation tasks. It is interesting to find out whether these differences result from differences in innate spatial abilities or from differences in spatial competencies. In contrast to spatial abilities, spatial competencies can be improved through suitable training methods, thus lead to better spatial problem solving skills. In this paper, we tested the correlation of spatial abilities and navigation performance with egocentric, allocentric and landmark-based route instructions. The paper folding test and the hidden pattern tests did not yield any performance correlation. Mental rotation test showed only a significant correlation with the accuracy in egocentric route instructions. The accuracy performance of egocentric and allocentric route instructions was correlated, i.e. participants consistently showed a better performance with allocentric instructions if they were good at egocentric instructions and vice versa.

Studies like the present help to reveal more precisely which spatial abilities are needed to read maps for orientation and navigation. The limited correlations of spatial abilities with the performance of participants in the different route instructions suggest that performance in spatial tasks is not dominantly influenced by (innate) spatial abilities examined in the three employed tests. Spatial competencies that can be learned and improved through training might play an important role for the performance. We are currently conducting the same test with additional participants to increase the sample size as well as the reliability of the results. Tests to measure spatial competencies are to be developed to investigate the role of spatial competencies in spatial task performance and learning. A similar study may be conducted with the mobile version of Ori-Gami to compare the results to the impact of orientation in a real world environment. Games like Ori-Gami could be further developed to foster specific strategies and competencies for challenging and error-prone situations.

## References


1. Goodchild, M.: The fourth R? Rethinking GIS education. *ArcNews* 28, 5-7 (2006)
2. Committee on Support for Thinking Spatially: *The Incorporation of Geographic Information Science Across the K-12 Curriculum, N. R. C. Learning to think spatially*. National Academies Press, Washington, DC (2006)
3. Bartoschek, T., Bredel, H., Forster, M.: GeospatialLearning@PrimarySchool: A minimal GIS approach. *Proceedings of Sixth international conference on Geographic Information Science, Extended Abstracts.* (2010)
4. Battersby, S.E., Golledge, R., Marsh, M.: Incidental learning of geospatial concepts across grade levels: Map overlay. *Journal of Geography* 102, 231-233 (2006)
5. Marsh, M., Golledge, R., Battersby, S.E.: Geospatial Concept Understanding and Recognition in G6-College Students: A Preliminary Argument for Minimal GIS. *Annals of the Association of America Geographers* 97, 696-712 (2007)
6. German Association for Geography (DGFG): Educational Standards in Geography for the Intermediate School Certificate. Deutsche Gesellschaft für Geographie (DGfG) (2007)
7. Republic of Rwanda; Ministry of Education: Social studies curriculum for the basic education programme , grades 1–6. (2006)

8 . Hemmer, I., Hemmer, M., Neidhardt, E.: Räumliche Orientierung von Kindern und Jugendlichen – Ergebnisse und Defizite nationaler und internationaler Forschung. In: Geiger, M., Hüttermann, A. (eds.) Raum und Erkenntnis., vol. 66-78. Aulis Verlag Deubner, Köln (2007)
9 . Levine, M., Jankovic, I., Palij, M.: Principles of spatial problem solving. *Journal of Experimental Psychology: General* 111, 157-175 (1982)
10 . Presson, C.C., Hazelrigg, M.D.: Building spatial representations through primary and secondary learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 10, 716-722 (1984)
11 . Roskos-Ewoldsen, B., McNamara, T.P., Shelton, A.L., Carr, W.: Mental representations of large and small spatial layouts are orientation dependent. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 24, 215-226 (1998)
12 . Rossano, M.J., Warren, D.H.: Misaligned maps lead to predictable errors. *Perception* 18, 215-229 (1989)
13 . Rossano, M.J., Moak, J.: Spatial representations acquired from computer models: Cognitive load, orientation specificity and the acquisition of survey knowledge. *British Journal of Psychology* 89, 481-497 (1998)
14 . Presson, C.C., De Lange, N., Hazelrigg, M.D.: Orientation specificity in spatial memory: What makes a path different from a map of a path? *Journal of Experimental Psychology: Learning, Memory, and Cognition* 15, (1989)
15 . Levine, M., Marchon, I., Hanley, F.: The placement and misplacement of you-are-here maps. *Environment and Behavior* 16, 139-158 (1984)
16 . Klippel, A., Freksa, C., Winter, S.: You-are-here maps in emergencies: The danger of getting lost. *Journal of Spatial Science* 51, 117-131 (2006)
17 . Montello, D.R.: You are where? The function and frustration of you-are-here (YAH) maps. *Spatial Cognition and Computation* 10, 94-104 (2010)
18 . Milson, A., Demirici, A., Kerski, J.: *International Perspectives on Teaching and Learning with GIS in Secondary Schools*. Springer (2011)
19 . Mohler, J.L.: A review of spatial ability research. *Engineering Design Graphics Journal* 72, 19-30 (2009)
20 . Hegarty, M., Keehner, M., Khooshabeh, P., Montello, D.R.: How spatial abilities enhance, and are enhanced by, dental education. *Learning and Individual Differences* 19, 61-70 (2009)
21 . Hegarty, M., Waller, D.: Individual differences in spatial abilities. In: Shah, P., Miyake, A. (eds.) *The Cambridge handbook of visuospatial thinking*, pp. 121-169. Cambridge University Press, Cambridge, England (2005)
22 . Hegarty, M., Montello, D., Richardson, A.E., Ishikawa, T., Lovelace, K.L.: Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning. *Intelligence* 34, 151-176 (2006)
23 . Moffat, S.D., Hampson, E., Hatzipantelis, M.: Navigation in a “virtual” maze: Sex differences and correlation with psychometric measures of spatial ability in humans. *Evolution and Human Behavior* 19, 73–87 (1998)
24 . Waller, D.: Individual differences in spatial learning from computer-simulated environments. *Journal of Experimental Psychology* 6, 307-321 (2000)
25 . Münzer, S., Stahl, C.: Learning routes from visualizations for indoor wayfinding: Presentation modes and individual differences. *Spatial Cognition and Computation* 11, 281-312 (2011)
26 . Ekstrom, R.B., French, J.W., Harman, H.H.: Manual for kit of factor-referenced cognitive tests. . *Educational Testing Service*, Princeton, NJ (1976)
27 . Hegarty, M., Waller, D.: A dissociation between mental rotation and perspective-taking abilities. *Intelligence* 32, 175-191 (2004)
28 . Kozhevnikov, M., Hegarty, M.: A dissociation between object-manipulation spatial ability and spatial orientation abilities. *Memory and Cognition* 29, 745-756 (2001)
29 . Jansen-Osmann, P., Heil, M.: Suitable stimuli to obtain (no) gender differences in the speed of cognitive processes involved in mental rotation. *Brain and Cognition* 64, 217-227 (2007)
30 . Thurstone, T.G.: *Manual for the SRA primary mental abilities*. Science Research Associates, Chicago, USA (1958)