# Meta-Representational Competence as an Aspect of Spatial Intelligence

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**Abstract**

Meta-representational competence (diSessa, 2004) encompasses ability to choose the optimal external representation for a task and to use novel external representations productively. Research on this aspect of spatial intelligence reveals large individual differences in ability to adaptively choose and use external visual-spatial representations for a task. This research suggests that we should not just think of interactive external visualizations as ways of augmenting spatial intelligence, but also consider the types of intelligence that are required for their use.
**Keywords:** Spatial ability; intelligence; external representations.

## Introduction

The concept of spatial intelligence brings to mind measures of individual differences in spatial ability, which measure performance in tasks (e.g., mental rotation, paper folding) involving the storage and manipulation of internal spatial representations While this is certainly a central aspect of spatial intelligence, with developments in information technologies, spatial thinking increasingly involves interacting with external visualizations. For example, medical students now learn three dimensional (3-D) anatomy by interacting with computer visualizations that they can rotate at will, scientists gain insight into their data by visualizing and interacting with multidimensional plots, and chemists use a variety of external representations, including 3-D physical and virtual models and 2-D diagrams, to reason about the structures and reactive properties of molecules. While new technologies are typically seen as means of augmenting human intelligence, this paper considers the ways in which they also make new demands on our intelligence.

diSessa (2004) coined the term *meta-representational competence* to encompass ability to choose the optimal external representation for a task, use novel external representations productively, and invent new representations as necessary. This competence goes beyond the capacity to understand the conventions of a particular type of representation (such as a graph, map, or diagram). It is a form of metacognition about visual-spatial displays. diSessa was mostly concerned with children's native representational competence in using and inventing scientific representations, and how to foster this in instruction. In this paper, I consider meta-representational competence as a component of adult spatial intelligence.

## Using Representations

In one line of research inspired by the use of new technologies in medicine, I and my colleagues have found large individual differences in use of interactive visualizations (Cohen & Hegarty, 2007; Keehner, Hegarty, Cohen, Khooshabeh & Montello 2008; Stull, Hegarty & Mayer, 2009). In a series of studies, participants were given the opportunity to manipulate a virtual 3-D object while accomplishing a spatial task, namely inferring the appearance of a cross section of the 3-D object. On each cross section trial, participants were shown a picture of the 3-D object with a line drawn through it, and an arrow pointing to the line and their task was to draw the cross section that would result if the object were sliced at the line and one was viewing the cross section from the direction of the arrow.

The most common use of the virtual object was to rotate it to the view of the object that one would see if one was viewing it from the perspective of the arrow. Rotating the external visualization in this way relieves the participant of the need to mentally rotate the object or mentally change his or her perspective with respect to the object. Participants who used the model in this way had better performance, but many students did not use the model. In general, there were large individual differences in ability to discover how to best use the virtual object, ability to actually manipulate it, and ability to benefit from the most task-relevant view of the object.

We are finding similar results in current studies on use of 3-D models in chemistry (Stull, Hegarty, Dixon & Stieff, submitted). In these studies the task (for chemistry students) is to translate between different diagrams of molecules that use different conventions to depict the 3-D structure of molecules in the two dimensions of the printed page, and depict the molecule from different spatial perspectives. On each trial participants are given one diagram of a molecule and their task is to draw a different diagram of the same molecule. The most common use of the model is to first match it to the perspective of the given diagram, then rotate it to match the perspective of the diagram to be drawn, and then draw this diagram. However, when they are provided with a concrete 3-D model of the molecule, many students do not use the model and perform poorly on the representation translation task. These studies indicate that ability to use an external representation is not always a given, and provide evidence for individual differences in adult meta-representational competence.

## Choosing Representations

Another aspect of meta-representational competence is choosing the most effective representation for a given task. We have examined this aspect in the domain of meteorology. The design of a weather map, such as its complexity or the relative salience of different depicted variables, can have significant effects on performance of map comprehension tasks (Canham & Hegarty, 2010; Fabrikant, Rebich-Hespanha & Hegarty, 2010; Hegarty, Canham & Fabrikant, 2010). However, when given a choice of displays, people do not always choose the optimal display for their task. In a series of studies we asked naïve undergraduate students and experienced weather forecasters to perform read-off and inference tasks with maps that varied in complexity (the number of displayed variables) and realism (the extent to which they looked like their real-world referents). We also asked our participants to choose (from a set of maps varying in complexity and realism) the maps that they would prefer to use when accomplishing these tasks.

Both naïve students and experienced forecasters performed the tasks more efficiently with simple maps that displayed only the task-relevant information and naïve students were more accurate with these displays. When asked to choose which map they would prefer to use, or the map with which they would be most efficient, the majority also chose these relatively simple maps. However about one third of naïve students and expert weather forecasters chose more realistic and complex weather maps than they needed, even though complexity and realism impaired performance (Hegarty, Stull & Smallman, in press; Hegarty, Smallman, Stull & Canham, 2009). More generally, surveys of undergraduate students indicate that they prefer realistic, animated, and detailed displays over more abstract, static, and sparse displays for a range of tasks (Hegarty, 2010; Hegarty et al., 2009).

## Conclusions

It is important to consider the broader context of these research findings. For example, efficiency may not be an individual's paramount goal when he or she chooses a visual display. There is also a tradeoff between the time required to find or design the most efficient display and the time saved by using that display. Finally, complex displays that are less efficient in the short term may lead to a more elaborated understanding of the situation represented by the display

Nevertheless, these studies highlight the fact that although new visualization technologies have the potential to augment human spatial intelligence, intelligence is also required for their use. With the current interest on how to foster spatial intelligence, (National Research Council, 2006) and increased availability of complex visualizations, they suggest that more attention should be paid to teaching people to use, design, and critique external spatial representations, in addition to training their internal visualization abilities.


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