Educating Spatial Thinking for STEM Success

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Overview

In recent years there has been new recognition of the importance of spatial thinking in Science, Technology, Engineering and Mathematics (STEM) disciplines, in part because of evidence that spatial ability predicts success and persistence in STEM (Wai, Lubinski & Benbow, 2009), but is not fostered in our educational systems (National Research Council, 2006). Based on this evidence, current approaches aim to increase science achievement by training the types of general spatial skills measured by spatial ability tests. However, although there is considerable evidence that these spatial skills can be trained (Uttal, et al., 2013), there has been little evidence to date that training of general spatial skills transfers to success in STEM disciplines (Stieff & Uttal, 2015).

In this symposium, we will take a critical approach to issues of how to educate spatial thinking, both by raising some theoretical questions about the nature of spatial thinking in STEM, and by considering a range of different approaches to enhance the development of spatial thinking at different educational levels (elementary, secondary, and college) and in different STEM disciplines. The participants will discuss a broad range of spatial challenges faced by students in STEM learning, including mastering discipline-specific spatial language, novel visuospatial representations, and the interplay between visualization and analytic reasoning strategies.

The four talks will be by researchers that differ in disciplinary expertise, methodologies, and theoretical frameworks. David Uttal, an expert in cognitive and developmental psychology will describe a program that develops 12th grade students' spatial skills through the use of Geographic Information Systems (GIS). Mike Stieff, an expert in chemistry and learning sciences will describe how he has used theories of representational competence to design laboratory studies and classroom interventions that improved spatial thinking in college-level chemistry by targeting students' understanding of domain-specific visuospatial representations. Tom Lowrie, an expert in mathematics education and assessment will describe an intervention conducted by elementary school teachers in the Australian school system, which improved students' spatial reasoning and transferred to mathematics achievement. Stella Vosniadou will describe laboratory studies that provide evidence for a shift from visual-spatial to analytic thinking with expertise in Geometry and Chemistry. She will interpret these results as an instance of conceptual change that raises questions about the relationship of spatial reasoning to STEM problem solving as learning progresses. Mary Hegarty will introduce the topic, moderate the symposium and lead a discussion on lessons learned about the nature of spatial thinking and how it can be best fostered in our educational systems.

Training Spatial Problem-Solving (David Uttal)

Many studies have demonstrated that spatial skills strongly predict STEM achievement and attainment, and that spatial skills can be improved through training and experience (e.g., Uttal et al., 2013). However, most of these studies have focused only on psychometrically-assessed spatial skills, such as mental rotation. Although important, it seems likely that STEM skills will involve more than these core skills. For example, learning STEM will involve *higher-order* spatial skills, such as reasoning about patterns and distributions, and determining how best to represent and make decisions about spatial data. Therefore, we have created a program that emphasizes the usual of spatial data and extensive mapping challenges with Geographic Information Systems (GIS) to facilitate the development of higher-order spatial skills (Jant et al, 2013). 12th-grade students in several high schools completed the curriculum. They demonstrated improvement in spatial reasoning and more general scientific problem solving, indicating that higher-order spatial skills can be enhanced.

Improving Spatial Thinking in STEM through Representational Competence (Mike Stieff)

Using the domain of chemistry as a context, I will explore the design of interventions that enhance spatial thinking by improving students' representational competence (i.e., skills related to interpreting, transforming, and creating visuospatial representations). Spatial thinking with visuospatial representations is central to learning and problem solving in all STEM fields. Students with low spatial ability have more difficulty interpreting visual representations in STEM courses, fueling deficit models of who can succeed in STEM fields and motivating educational interventions that aim to train general spatial ability independent of disciplinary content. Interventions developed in my laboratory include alternative strategy training (Stieff, et al. 2014), modeling activities (Stieff, et al., 2016a) and gesture (Stieff, et al., 2016). Each intervention has yielded significant improvements in representational competence and student achievement on spatially-demanding assessments. In three experiments, I will show that representational competence is highly responsive to instruction and demonstrate that students who might otherwise be excluded from STEM degree programs based on their spatial ability can attain successful learning outcomes with appropriate support.

Developing Spatial Reasoning Programs for STEM learning: Empowering Classroom Teachers to Embed Intervention into Practice (Tom Lowrie)

Although there has been considerable research on how to improve spatial ability, few studies have considered the effect of spatial training on STEM learning (Stieff & Uttal, 2015); despite evidence that improving spatial thinking can improve skills necessary to succeed in STEM disciplines (Uttal, et al., 2013). In fact, even very limited spatial training seems to improve student's mathematics skills (Cheng & Mix, 2014). However, current spatial intervention programs are not likely to have much impact on school curricula, since the training is not embedded within daily classroom practices. Recently, a classroom-based spatial intervention study demonstrated improvements in students' spatial and mathematics performance (Lowrie, Logan & Ramful, in press). The intervention was implemented by students' own classroom teachers. This presentation will focus on the need for spatial intervention programs to be framed around meaningful pedagogical frameworks, informed by cognitive science, aligned to school curricula, and implemented by classroom teachers.

The Paradoxical Relation between Spatial Reasoning and Success in STEM (Stella Vosniadou)

I will present results from two studies which used a visual/analytic strategy task to investigate changing relations in the adoption of visual/spatial and analytic strategies in geometry and chemistry. The results showed that a) there is increasing reliance on the adoption of analytic strategies with the development of domain expertise (see also Stieff et al., 2014), and b) that this reliance seems to depend on domain knowledge rather than on individual differences in spatial reasoning (Kospentaris et al., 2016; Vlcacholia et al., 2015). Given the convincing evidence that spatial reasoning abilities can predict success in STEM disciplines (Wai et al., 2009), the finding that problem solving in expert scientists increasingly relies on specialized, domain-specific analytic approaches raises important questions about the exact relationship between spatial reasoning and scientific problem solving.

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