Spatial Cognition and STEM Education: What, When, and Why?

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Outline

• Spatial ability strongly predicts STEM achievement
• But why?
• Is spatial training likely to be an effective intervention to
  – Enhance STEM achievement and attainment
  – Or prevent dropout
• How malleable is spatial thinking?
Wai, Lubinski, & Benbow, 2009
But Why?

• Two models and a compromise, reformation
  – A) “Global Model” (Stieff); “Space Uber Alles”
  – B) “Localized Model”; Domain-specificity

  – A radical middle
    • Psychometrically-assessed spatial skill matters a great deal early on in STEM learning
    • Becomes less important as domain-specific knowledge is acquired

• Shifts in representation, processing
  – Lessons from chess and Scrabble
Important to keep separate

Attainment versus Achievement
The “Global Model” of spatial thinking in STEM

M. Stieff
But it turns out not to be true

At least at the expert level
Spatial ability tends *not* to predict expert performance

Stieff, The Localized Model
So, does this mean that domain-specific model is correct?

- Reasons to be sad if this is really, radically true
  - No transfer
  - Really hard to know how and when to help people
Domains to consider

- Geoscience
- Chemistry
- Dentistry
- Physics (a little bit)
- Chess
- Scrabble
Hambrick et al., in press

Not just Restriction of Range

![Graph showing the relationship between Map Accuracy (%) and Visuospatial Ability (Low vs. High), with lines indicating High GK and Low GK performance.]
RIMRT – Stimuli
(Stieff, 2004, 2007)

Shepard-Metzler Objects

3D Ball-and-Stick Models

Structural Diagrams

Stereo Diagrams
Students Do Use Mental Rotation for Asymmetrical Objects

- For Block Shapes and Molecular Diagrams, a positive linear relationship between response time and angular disparity indicated mental rotation
- Use of mental rotation is independent of stimulus presentation

*Figure 34 Aggregated linear relationships for both conditions in Study #1.*
Figure 6. Aggregated responses by experts who used the learned heuristic.
Dentistry

- More nuanced
- But, overall, spatial ability becomes less predictive, domain-specific abilities become more important
Physics

• Kozhevnikov, Hegarty, & Mayer, 2002
• Kozhevnikov & Thornton, 2006.
Chess and Scrabble

• STEM expertise is more like chess than like Scrabble

• Spatial skills do not predict performance at the expert level in chess (Holding, 1985; Waters, Gobet, & Leyden, 2002)

• But spatial skills do predict performance among champions in Scrabble (Wai and Halpern)
What’s a chunk?

• Spatial template
• More abstract?
Attack and Defense
A Foil: Expertise in Scrabble™

Wai and Halpern
When does spatial cognition matter in expert STEM performance?
Watson and Crick

http://www.spatialintelligence.org
STEM to STEAM

Rhode Island School of Design
Interim Summary

• Strong, convincing correlations of relation between (psychometrically-assessed) spatial ability and STEM attainment
• But weak, inconsistent correlations between spatial ability and expert performance
• Global model isn’t right
• But if the domain specific model is right, how do we get those correlations?
Wai, Lubinski, & Benbow, 2009
Answer

- Spatial ability limits who can go into STEM
- The catch-22 of low spatial skills
FIGURE 3. Hazard function for first-time-in-college students matriculating in engineering
Life-Table Survival Function Estimate

<table>
<thead>
<tr>
<th>semester</th>
<th>Survival Probability</th>
</tr>
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<tr>
<td>0</td>
<td>1.00</td>
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<tr>
<td>5</td>
<td>0.78</td>
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<td>7.5</td>
<td>0.68</td>
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<tr>
<td>10</td>
<td>0.58</td>
</tr>
<tr>
<td>12.5</td>
<td>0.48</td>
</tr>
</tbody>
</table>

No. of Subjects | Event | Censored
---|---|---
100179 | 22% (21943) | 78% (78236)
Possible Mechanisms

• Spatial ability required to perform introductory tasks
• Mediating role of drawing and visualizations (Hegarty et al.)
If I’m right

• The case for spatial training or preparation is actually stronger than for either the Global or Localized (Domain-specific model)

• Helps to constrain, specify when and why spatial training might help.
How Malleable is Spatial Ability?

(Answer = .43 SD)
How training might help: Object manipulation and transformation

- Increasing recognition of objects
- Attentional capacity
- Memory capacity
- Reduced processing time for transformations (e.g., rotation)
- (Meta) knowledge of the importance of spatial representations and reasoning
Typology of Spatial Skills

Intrinsic (Within Object)

Extrinsic (Between Objects)

Static

Dynamic
To be a “hit”, a study needed one term from column A, and one from column B.

**Column A**
- training
- practice
- education
- “experience in”
- “experience with”
- “experience of”
- instruction

**Column B**
- “spatial relation”
- “spatial relations”
- “spatial orientation”
- “spatial ability”
- “spatial abilities”
- “spatial task”
- “spatial tasks”
- visuospatial
- geospatial
- “spatial visualization”
- “mental rotation”
- “water-level”
- “embedded figures”
- horizontality
Sample

• Included 217 studies
  • About 54% unpublished (addresses “file drawer” problem)

• 12 were removed as outliers: at least 2.5 SD above the mean
  - Negatively correlated with Human Development Index ratings
Effect sizes

• Standard measure of efficacy *across* studies
  – Mean change as a result of training or experience, expressed in standard deviation units.
  
  $g_{T_c} = \frac{M_{\text{treatment}} - M_{\text{control}}}{\text{vMSE within S’s}}$

• "T_c" refers to Treatment group relative to Control group
Results
Training works
Training lasts
Training transfers
Training works

- Mean effect size = \(0.47\) (i.e., almost a 1/2 SD of improvement)
- “Moderate” improvement (Cohen, 1988)

For IQ (SD = 15), \(0.47\) SD would be an increase of about 7.0 points.
Figure X: Funnel plot of study-average effect sizes, using study-average variances. The funnel indicates the 95% random effects confidence interval.
Training lasts

- Post-tests taken immediately after training demonstrated approximately equivalent improvement to delayed post-tests.
- No significant decline in effect size measured immediately, within 1 week, within 1 month and over 1 month.
Training transfers

• The overall effect size for transfer was .48
  → YES, training transfers

Is There a Difference Between Near and “Medium” Transfer for Spatial Gains?

• Near transfer = Training and post-test were highly similar. For example: Water level task using round flask to water level task using irregular flask.

• Medium transfer = Training and post-test were different. For example: Mental Rotation training for a post-test of paper folding
Training transfers

- No difference between No Transfer, Near and Medium Transfer effect sizes
Training transfers

• Why does this matter?
  - Suggests training is NOT just a practice effect
  - If spatial training has effects that extend beyond mere practice, training should transfer to untrained tasks.

• Transfer:
  Tetris to Paper Folding Test (Terlecki, Newcombe, & Little, 2008)
Participant Characteristics

Initial level of ability
Sex differences
Age differences
Differences in Initial Level of Ability

- Studies that used only low spatial ability subjects showed significantly larger gains.
Sex differences

- Male advantage was present at pre and post test
  - No interaction between sex and training
Age differences

- At first glance, the histogram aligns with the traditional thinking that children improve more with training than adults.
- However these means are not statistically significantly different.
Age differences

• Despite a .17 advantage in effect size for children younger than 13, there is no significance due to variance within the Child group.
Differences in Dependent Variables

• Disembedding
• Mental Rotation
• Spatial Visualization
• Perspective Taking
• Spatial Perception
Substantial control group improvement

Particularly when control task is spatial in nature
Size of control group improvement explains a lot

• (some) variability across studies
  – Magnitude of effect often depends on CONTROL group
  – Syms and Meyer

• Malleability of spatial cognition

• Is It JUST test-retest?
  – Taking the test is a form of practice
  – Spatial filler effects hard to explain—not practicing the same thing
So what?
So what?

Training in theory could double the number of people “spatially qualified” to be engineers.
And at least some evidence it transfers to STEM

- Sorby
- Mix
- Some others
Promoting Spatial Problem Solving in Science Education

• The Geospatial Semester
• Robert Kolvoord, James Madison University
GOT LOCAL MILK?

Maryland & Virginia Milk Producers Cooperative Association, Inc.

Dr. Hannah Ponsary and Ryan Good
Lunay High School

Special Thanks to Maryland and Virginia Milk Producers Cooperation Association

Introduction

Milk is considered a staple food in many cultures worldwide. In Maryland and Virginia, we are fortunate to have local milk producers who provide high-quality milk to the market. This project aims to explore the local milk industry and map the milk supply chain from the farm to the processing plant.

Methods

For this project, we collected data from various sources, including online directories, local dairy associations, and direct observations. This data was used to create a map showing the distribution of milk producers and processing plants in Maryland and Virginia.

Results

We identified 20 milk-producing farms and five processing plants in the region. The map shows the proximity of farms to processing plants, indicating the efficiency of the milk supply chain.

Conclusion

By understanding the local milk industry, we can support local farmers and producers, ensuring a sustainable and healthy future for our community.

Legend

- Dairy Farms
- Processing Plant Routes
- Interstate

The Impact of Local Milk

Local milk production not only benefits producers but also consumers. By choosing local milk, we support our local economy and ensure the freshest and most nutritious milk available.

Acknowledgments

We would like to thank the Maryland and Virginia Milk Producers Cooperation Association for their support and guidance throughout this project.
Introduction

These are the ideal locations within the Shenandoah National Park that bears can be safely relocated away from towns. The project objective was to create buffers to help identify the areas where bears would be a nuisance to humans. Bear sightings have become more common in the state of Virginia because the population of bears, particularly Black Bears, has increased over the past years. Therefore, by taking steps to relocate nuisance bears these encounters can be decreased and the two species can live in the ecosystem with minimal problems. This project was of interest to us because of the high wildlife encounters and their large populations.

Analysis

We created buffers for developed areas both inside and outside of the Shenandoah National Park boundary. Within the park we followed features such as campgrounds and shelters. These areas are more likely to have bears and therefore needed buffers for the bears to help protect them from being hit by vehicles. These buffers, we believed, will not keep the bears from wandering into these locations. The buffers were created as a visual reference to locate the ideal site for relocation. Through this analysis of the Shenandoah National Park we found the locations, specifically the developed areas, were more susceptible to bears. We have also created buffers around nearby towns and other developed areas outside the park to help visualize areas that were more likely to have bears. We were surprised to find areas without developed areas that were appropriate bear relocation sites. We were anticipating fewer acceptable sites.

Hypothesis/Experiment

When we began our search for the best locations for bear relocation, we started off looking for the towns and cities that are in close proximity to the Shenandoah National Park. Using maps, we found areas where bears would be a nuisance. However, these areas were not as desirable as we had been hoping. The bears were found in areas where there were houses and other developed areas. We then looked at areas that were outside of the Shenandoah National Park. The areas were more suitable for relocation, as they were away from developed areas. Therefore, we decided to look at areas within the Shenandoah National Park, at the western entrance point, in only 10 miles wide. This, we thought, the number of these relocation areas would be limited.

Conclusion

In our assessment of the buffers we made around the roads, towns, developed areas, and developed areas we found that there were less locations suitable for relocating bears in the Shenandoah National Park. These relocation areas had to be located outside the buffered regions. They also require road access for a vehicle to get to the area. Therefore, it is highly recommended that a full-size vehicle is necessary for carrying a bear to these locations. The project has identified areas where bears can safely be relocated away from human development.

Sources

- Shenandoah National Park
- Virginia Wildlife Management
- NPS Shenandoah National Park
- Virginia Department of Game and Inland Fisheries
- Virginia Department of Natural Resources
- Virginia Department of Transportation
Spatial Language Increases Across the Course
Summary

• Neither the global or domain-specific model is entirely right
• Spatial thinking matters substantially early in STEM education
  – Less so with increasing expertise
• Spatial training works
• And might make a big difference
• But of course not all the difference
  – Meta-cognitive awareness, “Habit of Mind” (Liben)
And, of course, more research is needed!

- Large-scale correlations/econometric
  - Drop-out/Persistence correlated with spatial skills?
- Experimental
- Qualitative, process-oriented
Thanks

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