What does space look like in CS? Mapping out the relationship between spatial skills and CS aptitude

Jack Parkinson
jack.parkinson@glasgow.ac.uk
Centre for Computing Science Education
University of Glasgow
University of Glasgow School of Computing Science

Overview

Spatial Skills: cognitive skills relating to consolidation and understanding of space and spatial structures and operations

→ Spatial Encoding Strategy Theory: developing spatial skills leads to better strategies for encoding representations of non-verbal information and identifying landmarks to orient information

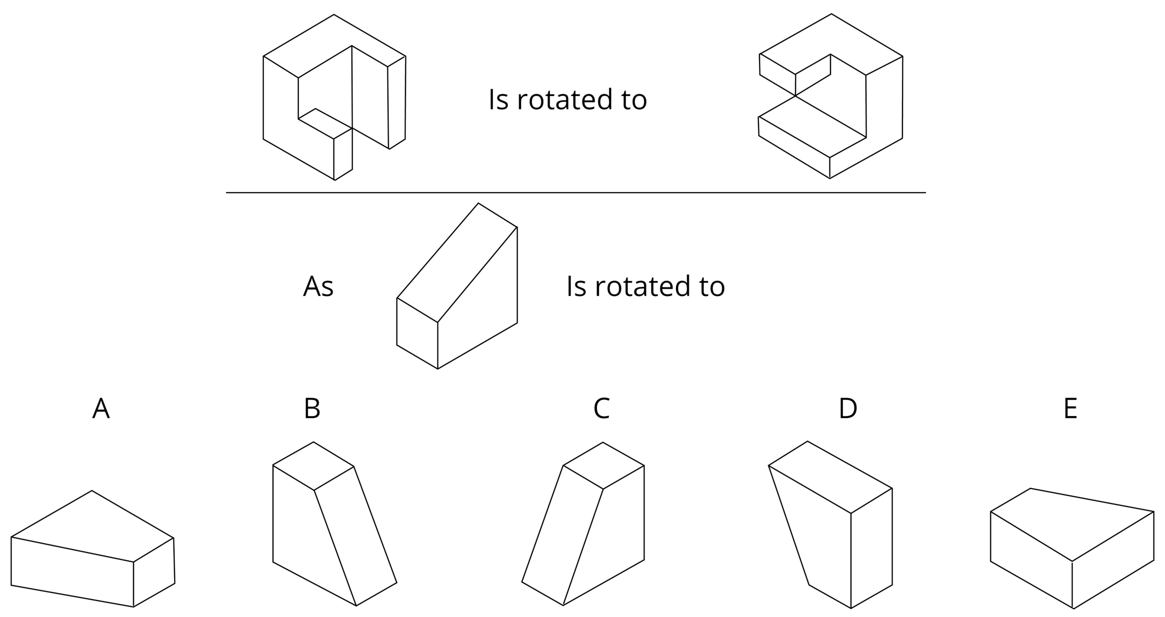
→ Effective chunking frees up WM space . More complex representations can be held at once. More information and multiple mental models can be held at once

→ How does this help in CS? How are these skills applicable?

?

What are Spatial Skills?

Spatial skills are cognitive skills relating to the mental consolidation and understanding of spatial structures and operations. Spatial tasks include rotating 3-dimensional objects, identifying patterns from obscured environments and using maps.



Spatial skills are associated with success in STEM domains. Students with better spatial skills tend to do better and academically progress further in several observed STEM subjects and degrees, and spatial skills training can appear to improve STEM outcomes (including CS specifically).

Spatial Skills and STEM Success: Spatial Encoding Strategy Theory

Lauren Margulieux [5] presents a theory for the relationship between spatial skills and success in STEM domains. The theory connects generalisable spatial skills with neuro structures in the hippocampus—grid and place cells—which are used to encode non-verbal information into pseudo-spatial representations.

This could apply to **all** non-verbal encoding, which is why spatial skills appear to be transferable across contexts where other apparently generic skills are not.

The theory states that:

Developing spatial skills (i.e., visualization, relations, and orientation) helps people to develop generalizable strategies for 1) encoding mental representations of non-verbal information, including 2) identifying useful landmarks to orient the representation.

Therefore, good spatial skills permit more non-verbal information to be encoded and oriented using up less working memory. This in turn allows more complex representations and more representations at a time to be held in memory.

A general, non-exhaustive set of skills which could be derived from Spatial Encoding Strategy theory are:

- The ability to hold ***multiple*** representations in one's head
- The ability to hold ***complex*** representations in one's head
- The ability to track ***overlapping*** or ***interconnected*** mental models

Since these skills can be traced back to non-verbal encoding strategies utilised in the grid and place cells, then it is possible that training one's spatial skills—and developing these strategies—will improve these skills too.

What does this look like in CS?

These skills—and this kind of language—have been used frequently in existing CS education research, with examples below. Therefore, I suggest that students with good spatial skills are more capable when it comes to the cases highlighted below thanks to their non-verbal encoding strategies, and developing these skills in students (perhaps before university-level study) will be valuable for them.

Loksa *et al.* describe a sequence of programming problem solving with steps which require students to maintain understanding or representations internally as they perform more operations, with two explicitly saying, "With a … solution in mind" [4]

Wing identifies a component of computational thinking as, "working with multiple layers of abstraction and understanding the relationships among the different layers", explicitly indicating that holding multiple representations at once is valuable [7]

Robbins examines Dual Process Theory as a context for exploring cognition in CS. Of particular interest is the application of System 2, the "slow, reflective" system which encompasses WM and mental models, and is argued to explain successes in multiple CS contexts [6]

In Cutts *et al.*'s Abstraction Transition Taxonomy, students must maintain and transition between several layers of abstraction in order to answer coding questions [1]

Duran *et al.* examine program complexity and define *plan depth* and *maximal plan interactivity*, both of which describe holding (multiple) complex schemas in memory at once [2]

In 2012, Mark Guzdial wrote a blog post (after reading Juha Sorva's PhD thesis) on defining CER, which he ultimately states as: "Computing education research is about understanding how people develop robust models of notional machines, and how we can help them achieve those mental models" [3]

Add your own ideas

References

1. Quintin Cutts, Sarah Esper, Marlena Fecho, Stephen R. Foster, and Beth Simon. 2012. The abstraction transition taxonomy: developing desired learning outcomes through the lens of situated cognition. In ICER '12: 2012 International Computing Education Research Conference, September 10-12, 2012, Auckland, New Zealand. ACM, New York, NY, USA, 63–70. https://doi.org/10.1145/2361276.2361290
2. Rodrigo Duran, Juha Sorva, and Sofia Leite. 2018. Towards an Analysis of Program Complexity From a Cognitive Perspective. In ICER '18: 2018 International Computing Education Research Conference, August 13–15, 2018, Espoo, Finland. ACM, New York, NY, USA, 10 pages. https://doi.org/10.1145/ 3230977.3230986
3. Mark Guzdial, Computing Education Research Blog. 2012. Defining: What does it mean to understand computing? Retrieved July 25, 2022 from https://computinged.wordpress.com/2012/05/24/defining-what-does-it-mean-to-understand-computing/
4. Dastyni Loksa, Amy J. Ko, Will Jernigan, Alannah Oleson, Christopher J. Mendez, and Margaret M. Burnett. 2016. Programming, Problem Solving, and Self-Awareness: Effects of Explicit Guidance. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems. ACM, San Jose California USA, 1449–1461. https://doi.org/10.1145/2858036.2858252
5. Lauren E Margulieux. 2019. Spatial Encoding Strategy Theory: The Relationship between Spatial Skill and STEM Achievement. In Proceedings of the 2019 ACM Conference on International Computing Education Research. ACM New York, NY, USA, Toronto, Canada, 81–90. https://doi.org/10.1145/3291279.3339414
6. Anthony V. Robins. 2022. Dual Process Theories: Computing Cognition in Context. ACM Transactions on Computing Education (March 2022), 3487055. https://doi.org/10.1145/3487055
7. Jeannette M Wing. 2008. Computational thinking and thinking about computing. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 366, 1881 (Oct. 2008), 3717–3725. https://doi.org/10.1098/rsta.

Interactive reference list: jack-parkinson.com/icer2022bib

Read the abstract: jack-parkinson.com/icer2022abstract

Read more on spatial skills: jack-parkinson.com/research

Suggest additions to this poster online: jack-parkinson.com/icer2022contribute