Practitioner Research

Can Spatial Reasoning Skills Improve When Studied in an Online Environment?

by Shelly Leduke

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Spatial reasoning (SR) is one of three modules in a five week course that I developed for EASTCONN on behalf of the Eastern Connecticut Workforce Board (EWIB) to remediate the three main entry tests to Eastern CT's Manufacturing Pipeline.[1] Applicants who do not meet the 70% average requirement across Ruler Reading, Shop Math, and Spatial Reasoning[2] are required to attend this course before retesting. The SR test includes folding shapes, stacking blocks, figure comparison and disassembling-a-cube questions.

I initially developed the course to run in person and that model was successful. During COVID, my supervisor and I opted to try the course online but we didn't know if participants' 2D and 3D SR skills would improve as a result of Zooming in from home.

While the question addressed in this article concerns teaching SR in an online format, much of the success of that endeavor stems from what I did in the in-person course. Because I did not consider myself to be very good at SR, and I certainly didn't know how it should be taught, I did a lot of research before putting together that original class.

The first article I found was *Paying Attention to Spatial Reasoning* (Ontario Ministry of Education, n.d.), which gave me a background in understanding SR as an academic subject. It also confirmed the value of blending content from all three tests (Ruler Reading, Spatial Reasoning and Shop Math) in order to mimic the way they would use them on the job rather than separately, as they would be formally assessed. *Seeing Relationships* (Newcombe, 2013) gave me a place to begin writing the in-person SR curriculum and many of the activities. *The Role of 2D and 3D Mental Rotation* (Bruce & Hawes, 2014) contributed to my toolkit of activities and solidified the place for mental rotation, not just as a form of assessment but as a developmental necessity in teaching SR. The ELPSA Framework (Lowrie, Logan & Patahuddin, 2018) guided my sequencing of spatial reasoning activities from 2D through 3D. *The Impact of an Intervention Program* (Lowrie et al., 2018) encouraged me to gain some experience in what I was teaching as opposed to learning it along with students (although I am in no way an expert now on spatial reasoning) and also described effectively the difference between mental rotation (rotating an intact object in your mind) and spatial visualization (manipulating an articulated object in your mind), both of which are assessed on the Pipeline tests. The Spatial Skills Training video (Sorby, 2019) reinforced my decision to use snap cubes and isometric graph paper activities. Sorby introduces the idea that spatial reasoning can be taught and why adult females generally do not perform as well as males (and it's not because of biology).

Method

Students

Students in this course were customers of the Eastern Connecticut and other Connecticut workforce boards who were interested in manufacturing. They had taken the initial assessments for the Manufacturing Pipeline Initiative (MPI), but did not earn the 70% average necessary to move forward. Students are given a list of resources for self-study[2] and are offered my course. While most of the individuals in this study originally pre-tested in Ruler Reading, Spatial Reasoning and Shop Math, COVID interrupted a few clients who had taken a slightly different battery of tests whose specific subject areas had not yet been carried forward, with remediation, in the pipeline. To prevent a longer disruption to their progress, they were remediated in my class even though their pre-tests did not line up exactly with my content.

Most of the participants were male (10:3), and most, if not all, were between the ages of 19 and about 50. Of the 13 that I have pre- and post-tests for, my guess is that slightly over half were White, non-Hispanic and the rest were African American, Asian, or Hispanic. I neither asked nor kept specific records on this information. A few students got jobs along the way and did not post-test. Two were no-shows, and two passed but I do not have actual test scores and so they are not included in my results data. The Zoom course was capped at 10 students, but class size started at 5-8 students and ended at 4-5 students. The 13 individuals for whom I have complete data represent three different sessions of the course.

Modifications for a Zoom class

In modifying the in-person course to be taught online, three of the biggest changes were the creation of an at-home kit, a homework component, and the requirement that students have cameras on (and sometimes show their screen) during SR activities.

Home Kit

For the in-person course, I had office supplies and manipulatives that I shared with students. According to my research, there was no good way to teach SR without them, and there was no guarantee that students would already have what they needed. So, we made kits to send to their homes (see list in Appendix A). Of the office supplies listed, it's interesting to note that many of my students did not have access to any ruler besides the one we sent them.

The home kit contained a 33-page packet of printed materials (since many students would not have a printer at home) and several sheets of blank white and colored paper. Included in the printed materials were several kinds of graph paper, tangrams, and sets of shapes (see Appendix B for the list of printed materials). The original packet had also included two sets of pentominoes which we later removed, as the more useful tangrams served the same purpose. This packet, along with most of the other items in the kit, was specifically intended for the spatial reasoning portion of the course.

Homework Component

When I teach spatial reasoning in an in-person class, there is a lot of collaboration. Students work in pairs to examine manipulatives, trade and draw them, and help each other build models. Additionally, I support students by sitting next to them and modeling how to view objects, step-by-step, from different angles. None of these things can be done easily over Zoom. Therefore, giving students extra time and access to partners or helpers at their remote location, are two of the biggest reasons to ask students to do homework. Another reason is because we did not replace 100% of in-person class time with Zoom time and there would not have been enough time in class to complete everything. Finally, working on SR at home, including asking students to find and create models to use for practice, helps them generalize the learning to their own environments and so increases their time spent attending to spatial reasoning examples.

Cameras On

Whether or not to require students to have their cameras on during online instruction has been a big topic for discussion during COVID. No matter how an organization or individual teacher answers that question, figuring out a way to teach spatial reasoning without being able to see what a student is doing is beyond the scope of this class and my research. While I try to avoid answering the question, “Is this right?” (because I want them to answer that for themselves), I still need to be able to ask guiding questions or prompt students to ask questions that will help them make that determination. To do that, we need to see each other. The *Cameras On policy* is not so much a modification from the classroom version of my course but a necessity worth mentioning when planning online SR instruction.

Spatial Reasoning Scope and Sequence

This is how I taught spatial reasoning.

- Prep and policies: Home kit, homework, and cameras on.
- Philosophy
    - Focus on conceptual understanding and problem solving/critical thinking as opposed to memorizing and tricks.
    - Focus on accuracy and the ability to explain and justify answers. (In manufacturing, there is no answer key.)
    - Use the **ELPSA** framework, especially…
        - **E**xperience: Evoke out-of-school experiences.
        - Generalize content to the real world—SR phone apps, puzzles, putting away groceries, etc.
        - Use homework to facilitate differentiation and ensure sufficient practice.
        - **L**anguage: Students are going to ask, “Is this right?” Have them talk about how what they

have made compares to the benchmark. Answer their questions only if absolutely necessary.

- **P**ictorial: Send concrete manipulatives home and ask students to find even more examples there.
- **S**ymbolic: Use diagrammatic instructions for making the tangram and water balloon. Draw and design 2D versions of 3D models and vice versa.
- **A**pplication: Spatial Reasoning is math but also toys, art, and science! The more learners can see specific examples of SR in the world, the more they will notice it even more, and the more automatic practice they will get. I showed videos of mobiles, kinetic sculpture, and NASA tools.

- Spatial Reasoning Activities
  - Spatial Reasoning: Math and Me Survey
  - 2D—approximately four one-hour Zoom sessions plus homework
    - Make a tangram set
    - Geometric transformations
    - Mental transformations and reflections
    - Spatial visualization
    - Tangram puzzles
    - Shape layering
    - Simulated and sample tests
    - Transition from 2D to 3D
  - 3D—approximately seven one-hour Zoom sessions plus homework
    - Origami water balloons
    - 3D models and nets
    - 3D mental rotation
    - 3D models and isometric drawings
    - 3D spinning cubes
    - Make a T-rex
    - Simulated and sample tests
    - Transition from 2D to 3D

Student Comments about Water Balloon Assignment

Describe how the process of making the first water balloon was for you.

- **VM**: It was pretty easy. I was very comfortable and confident in the process. I think my product was really good.
- **MM**: I felt very lost as I was folding as to which side should be folded. When I first attempted I did not feel I would do it. My wife attempted to help with no success. My observation of this was one of confusion.

Describe how the process of making the second water balloon was different from the process of making the first.

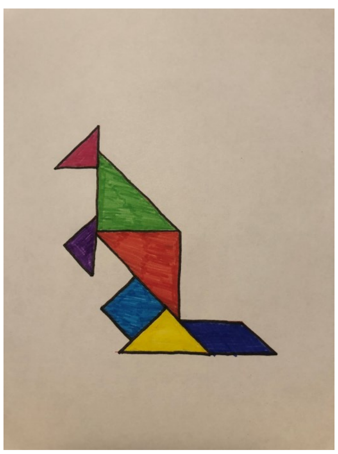
- **VM**: The second one I didn't need much instructions. I was more positive on this one.
- **MM**: I did not attempt this due to the issues I was having in class and when I attempted the first balloon on my own.

Now you have made a total of seven origami water balloons. Describe how the process of making balloons 3-7 was different than making balloon 1 and balloon 2.

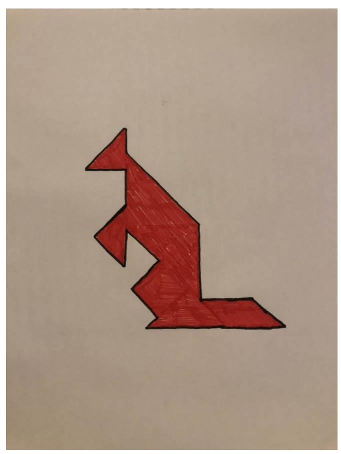
- **VM**: After the second I didn't need any instructions. Made each one in two mins. Even after a month I would have no problem. I learned to imagine shapes in my head. It will help me identify shapes by imagining them. (*Note: This student made a 27 point gain.)*
- **MM**: I'm not sure this exercise can even help me. *(Note: This student made a 43-point gain in SR, the highest overall gain and 10 points higher than the next highest gain.)*

Examples of Student Work

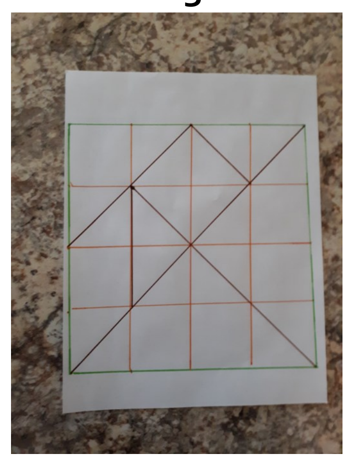
Tangram Puzzle



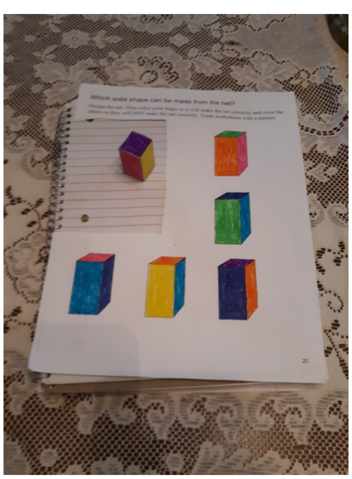
Composite Figure

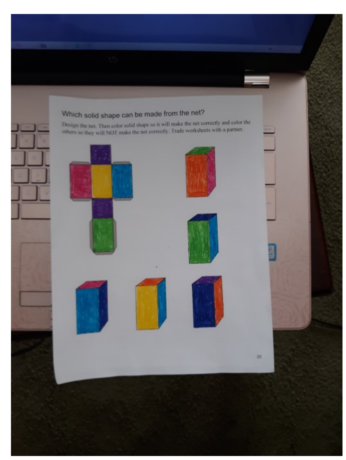


Optional Extension: Make a Tangram Set

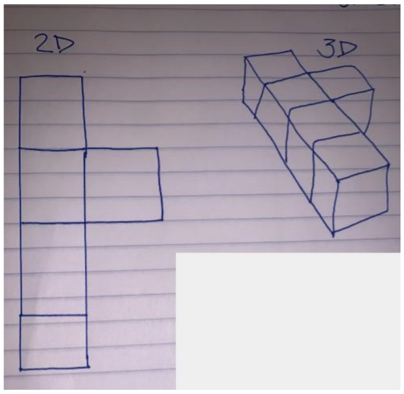


3D Models and Nets

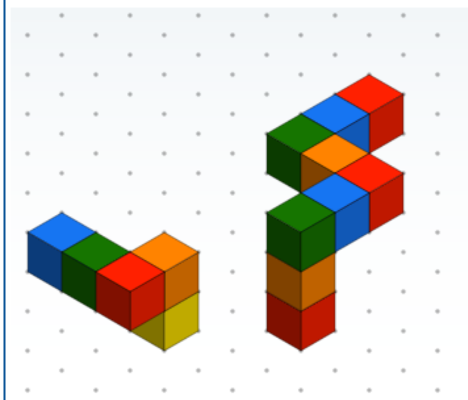




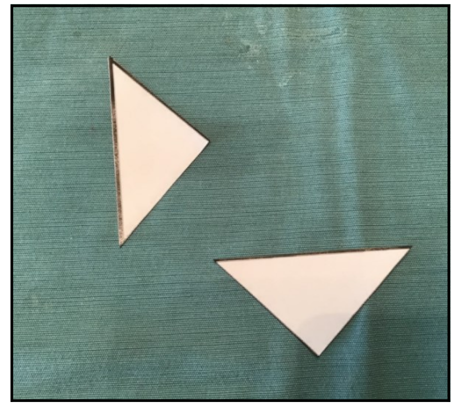
Transition from 2D to 3D



Isometric Drawings

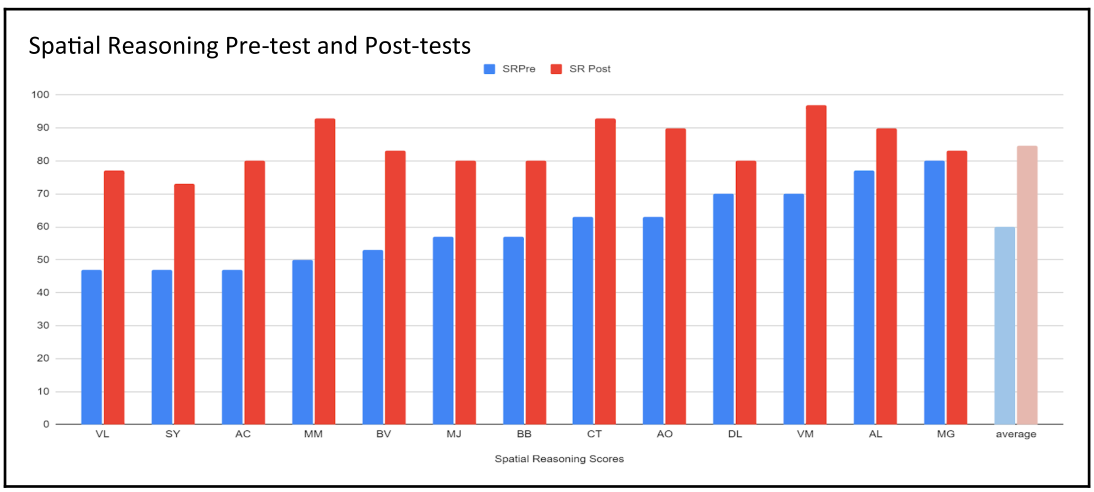


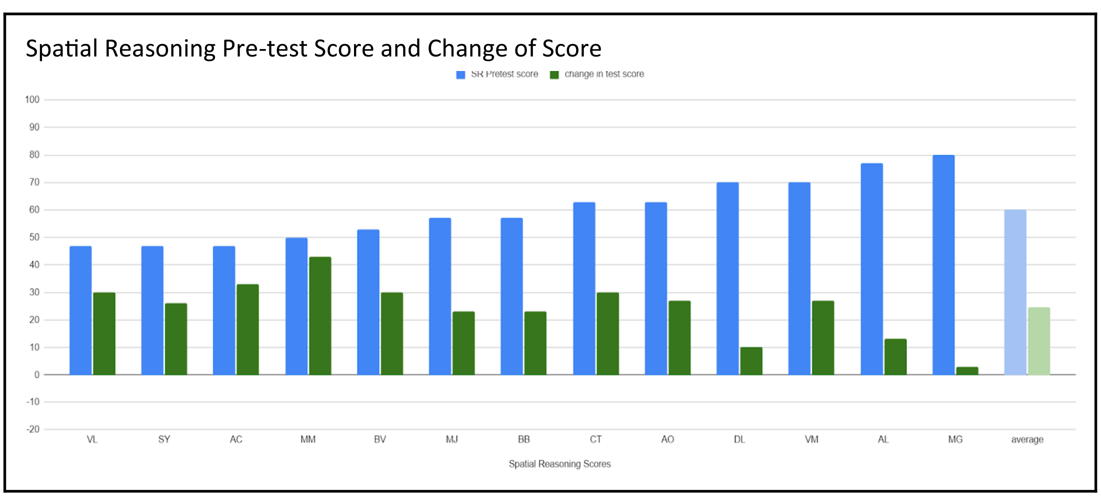
Geometric Transformations



Results

Everyone who has completed this course with me has achieved the required average score of 70% in Ruler Reading, Spatial Reasoning and Shop Math. Everyone's score in spatial reasoning increased (except possibly the two people for whom I only know their pass status). The average gain was 24 points, with the most significant gains earned by students with the lowest pre-test scores.





Discussion

Everyone improved their SR score, so we know it is possible to teach spatial reasoning in an online class. Also, everyone got at least a 73% on their post-test score, so SR didn't detract from anyone's required average score of 70%—their improvements were significant enough in the context of students' goals.

Since there was no control group in this project, it's not possible to know for sure whether the Homekit, Homework, Cameras On (HHCO) approach was what caused the increase in test scores. I trained another EASTCONN teacher to teach the course, and she shared informally that she did not do most of the hands-on activities after her first iteration but that everyone did fine. However, I no longer have those test scores for comparison. She is now training a new teacher to deliver the course. It would be possible in the future to examine how the course may have evolved and check the subsequent test scores to learn more.

Additionally, I did not teach SR in isolation. As I mentioned above in my discussion of the *Paying Attention* article (Ontario Ministry of Education, n.d.), including context adds to the effectiveness of SR instruction. Maybe it wasn't HHCO but the fact that we included SR when covering Ruler Reading (which they were better at than SR) and especially Shop Math (which we spent more time covering) that helped them.

Also, because I no longer have access to the in-person scores from before COVID, I can't compare them to the remote scores. Were the gains more or less significant than in person? I don't know. I used surveys at the beginning of class to capture students' knowledge and comfort with spatial reasoning. Next time I would administer them again at the end to capture more qualitative data.

Of the three modules of this MPI course, Spatial Reasoning was the one that I was most worried about when moving to a remote presentation because, according to the research, you absolutely need to have hands-on experiences in order to make progress. Given the success of the curriculum, I recommend continuing to offer it remotely to allow learners who have transportation or other issues to access the content, and to allow programs to combine their classes and share instructors so students in smaller districts can access the content.

Finally, continued research in the area of improving spatial reasoning skills for adults is essential. In the Sorby video mentioned earlier, the underrepresentation of women in STEM careers is attributed to how, compared with men, most women simply have not had the same rich experiences, beginning in childhood, that exposed them to spatial reasoning concepts. Although I can't remember which source this information is from, I know that the same is also true for people with limited financial resources (people of color are overrepresented in that category). Spatial reasoning skills are integral to success in math (see any of the resources I've cited), and math can be a stepping stone to success and financial independence. Having a good handle on spatial reasoning is relevant to *all* people, especially right now, in the U. S.

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[1]More information about Connecticut's Manufacturing Pipeline, funded by the Eastern Connecticut Workforce Investment Board (EWIBO) is available here. https://www.ewib.org/pipeline-faq

[2]More information on the content of the three MPI tests (and the remediation course) is available here. https://www.ewib.org/Portals/0/PDF/How2Study4MfgSkillsInventory.pdf The welding stream is optional for participants and welding content is not covered in this remediation course.

Appendix A

You will receive an at-home kit of supplies for this class.

- Have that kit with you for all classes.
- You will not need to have your camera on ALL the time during class, but you will need to be able to have it on for math activities so you can show what you're working on. You will also need to share your screen for some activities.

Math Home Kit

Each kit should contain:	
1	Packet of printed material including 10 sheets of colored paper and 10 sheets of blank white paper
1	Scissors
1	Glue stick
1	Tape
1	Ruler (any 12” ruler with 1/16 increments)
1 set	Snap cubes
1	4” mirror
1	Flashlight (removed from the list after the first run of the program)
1	3 ⅝” x 6 ½” envelopes
1 set	markers

Appendix B

The printed home-packet included:

- This t-rex foldable net (If Imgur is blocked for you at work, use a personal device)
- One-inch graph paper
- Half-inch graph paper
- Tangram directions (I used this one)
- A drawn tangram pattern to cut out. This differentiates the activity. Not everyone will be successful folding their own using the diagram directions.
- Isometric graph paper printed in dark black
- Isometric graph paper - triangles printed in black
- Isometric dot paper
- Several nets of different shapes (see an example of a “net” here)

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