PROJECT OUTCOMES REPORT

This project investigated the role of spatial thinking in learning and practicing hydrogeology — the study of water movement through the subsurface and its connections to surface water. Hydrogeologists must mentally synthesize data from maps, well logs, cross-sections, and contaminant concentration measurements to build a picture of what is happening underground. Despite the clearly visual, three-dimensional nature of the discipline, researchers had not previously identified which specific spatial thinking skills make this reasoning possible, nor how students develop and use these skills. This project addressed both questions over a four-and-a-half year period, producing empirical findings, validated tools, and professional development resources with direct application to hydrogeology education and workforce preparation.

Intellectual Merit

We recruited 72 participants ranging from undergraduate students to professional hydrogeologists with more than a decade of experience. Each participant completed a battery of validated spatial thinking tests, a hydrogeology knowledge assessment developed for the project, and a contaminated site characterization task — a realistic problem requiring participants to determine groundwater flow direction and predict contaminant movement through the subsurface. Using hierarchical regression modeling, we identified two spatial thinking skills that significantly predict performance: visual penetrative ability (visualizing interior structures from external clues) and working in multiple frames of reference (mentally holding and switching between different spatial perspectives simultaneously). Together with hydrogeology knowledge, these two skills accounted for nearly half of the variability in task performance. At low levels of hydrogeology knowledge, strong spatial thinking skills translated to more than a 25% performance advantage — a finding with direct implications for instruction.

A complementary qualitative study observed 26 upper-level geoscience students as they worked through the hydrogeology task in small groups, capturing their conversations, gestures, and use of manipulatives. The most challenging element was the potentiometric surface — an abstract concept describing the level to which groundwater would rise in a well. Students frequently confused it with land surface topography, struggled to visualize it as a three-dimensional object, and had difficulty drawing appropriate contour lines to represent it. Applying spatial thinking theory, we explain these struggles in terms of the cognitive demands of switching between intrinsic and extrinsic spatial thinking, and the challenge of reasoning about potential rather than actual water movement.

A third study examined how spatial thinking skills affect performance on the hydrogeology knowledge assessment itself. More than half of the assessment items required spatial thinking to complete, and spatial thinking skills predicted performance on those items — particularly for participants with greater experience. This finding has implications for how researchers and instructors design and interpret assessments across STEM fields.

Broader Impacts

The project produced two classroom-ready tools now available to the broader hydrogeology teaching community: the contaminated site characterization task and the hydrogeology knowledge assessment. Both are publicly available through the Towson University ScholarWorks repository. These tools give hydrogeology instructors a validated, research-based way to challenge students with authentic problems and measure their conceptual understanding — resources that did not previously exist for this discipline.

The project trained the next generation of researchers in geoscience education. At Towson University, four undergraduate students gained hands-on experience in human subjects research, data collection, and scientific communication. Graduate students at Western Michigan University, including the lead author of the third paper, developed advanced skills in quantitative and qualitative research methods as part of their doctoral training.

Results reached practicing educators directly. At the 2024 Earth Educators' Rendezvous, the team hosted a full-day workshop titled "Pedagogies and Practices for Boosting Spatial Understanding of Fluid Earth," attended by approximately 20 hydrogeology and fluid-Earth science instructors. Participants learned how spatial thinking skills affect student learning and explored evidence-based teaching strategies they could apply immediately. Findings were also shared across more than fifteen presentations at national conferences including the Geological Society of America, the American Geophysical Union, and the NSF IUSE Summit.

This work lays an evidence-based foundation for future development of curricula designed to help students who enter hydrogeology without strong spatial skills succeed in a discipline that society urgently needs. Current labor projections show greater-than-average workforce demand for hydrogeologists. Improving instruction in this field directly supports the preparation of a capable scientific workforce equipped to address challenges in water quality, contamination remediation, and sustainable water resource management.