Spatial Ability Development in the Geosciences

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Abstract

We designed an experiment to evaluate change in students' spatial skills as a result of completing an earth science course. Our test subjects included high school students in earth science classes, college level non-science majors enrolled in large enrollment introductory geoscience courses and introductory level geoscience majors. They also varied as to whether their course had a hand-on laboratory experience or used supplemental Geographic Information System (GIS) based activities. We measured all students' ability to mentally rotate three-dimensional objects and to construct a three-dimensional object from a two-dimensional representation before and after taking the earth science course.

Results show an improvement in spatial skills for all groups after completing the science course. We also observed a consistent improvement in spatial skills overall from high school level science to courses for majors, which is possibly related to their increased exposure to science. A subgroup of the test subjects among both high school and the college non-science majors completed supplementary GIS activities. The GIS implementation at the high school level was more extensive and resulted in significant improvements in both categories of spatial ability. At the college level, the non-science majors that used the GIS curriculum showed no significant difference from those that did not, probably because the time spent on the curriculum was too short. At the college level, the geoscience majors had nearly three times the improvement of non-science majors in both categories of spatial ability. This can most likely be attributed to hands-on, weekly laboratory experiences, which were not part of the course for non-science majors. Students choosing science majors typically have much higher spatial skills than the average first or second year non-science major, however there were large variations in spatial ability within all groups. These results suggest that we evaluate teaching strategies in all courses to ensure that students can interpret and understand the visual imagery used in lectures.

Teaching with GIS

A GIS allows students to manipulate and interrogate two-, three- and four-dimensional visualizations in ways not possible with traditional maps, photographs and satellite imagery. Exploring spatial and temporal relationships in geologic data has the potential of developing visualization skills as students view both two- and three-dimensional representations of earth processes. For example, a GIS allows quantitative and visual searches and queries of spatial data sets, as well as changes in data symbolization and overlay of different data sets to reveal new relationships.

Two GIS modules were completed by students at the high school and college levels. The first, Exploring the Dynamic Earth, consists of five units covering the topics of plate tectonics and geologic hazards. Examples of topics in the modules are shown in figure 1.

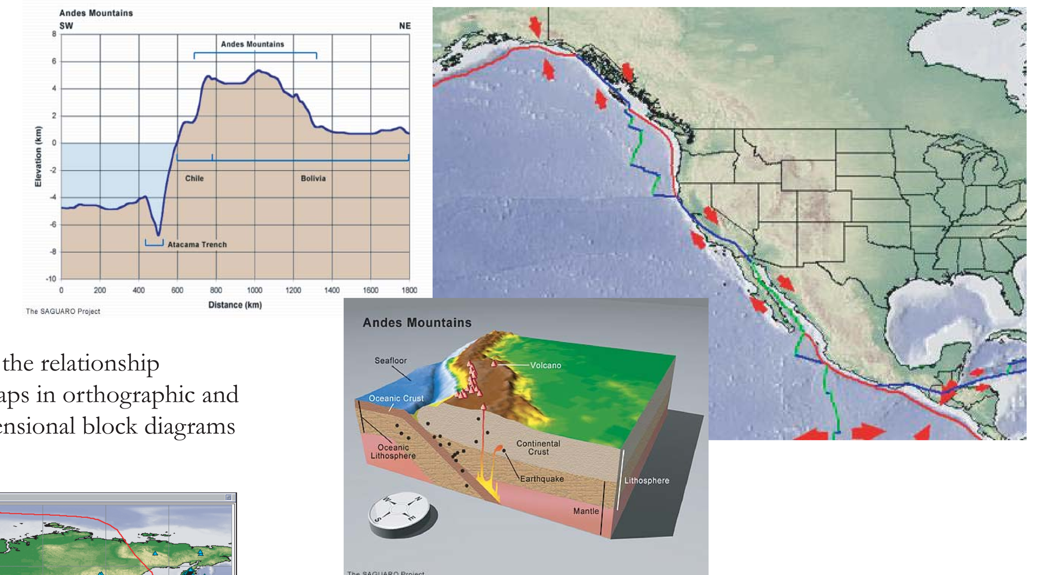
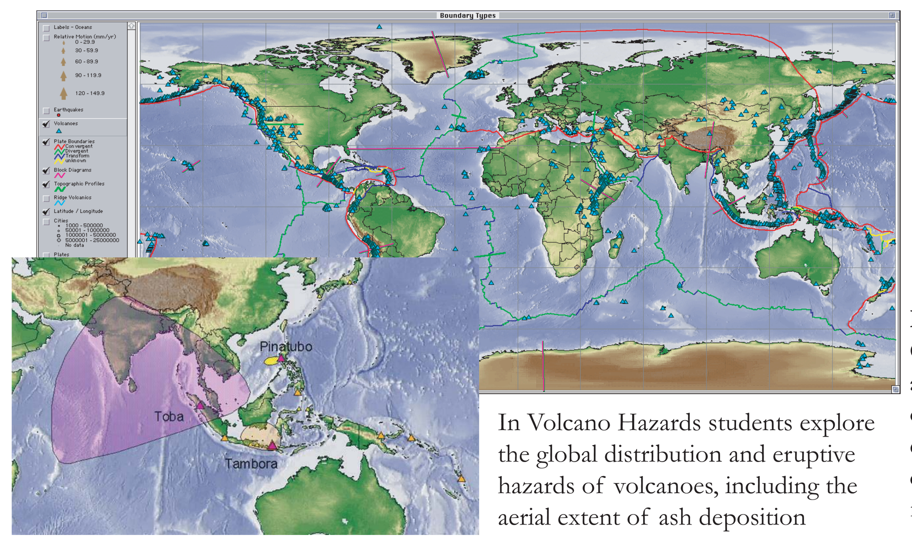


Figure 1. In Searching for Evidence students explore the relationship between topography and the plate boundaries using maps in orthographic and geographic projections, shaded relief maps, three-dimensional block diagrams and two-dimensional cross sections



In Volcano Hazards students explore the global distribution and eruptive hazards of volcanoes, including the aerial extent of ash deposition

The second GIS module, Exploring Tropical Cyclones, is a four-unit exploration of tropical cyclones. An example topic is shown in figure 2.

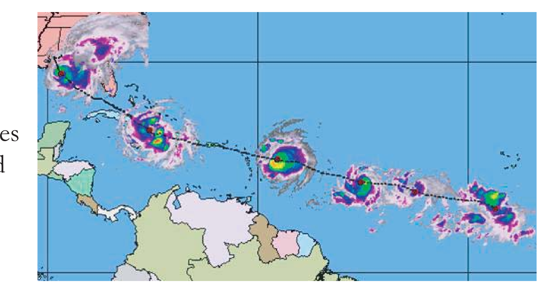
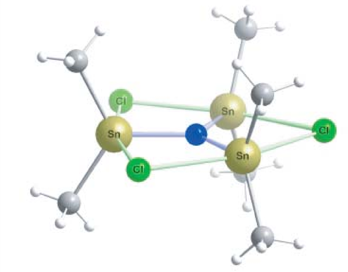


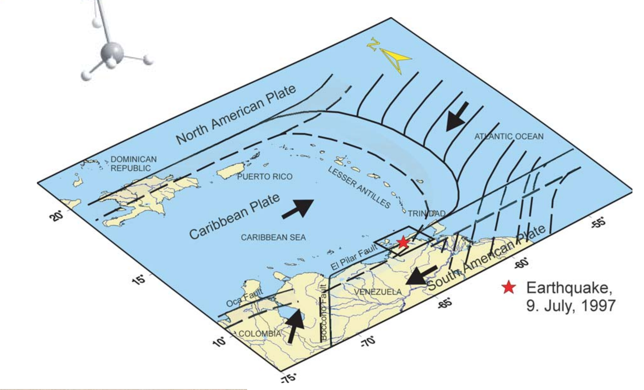
Figure 2. In Recipe for a Cyclone, students view animations of satellite images of hurricane movement and explore the spatial distribution of cyclone formation

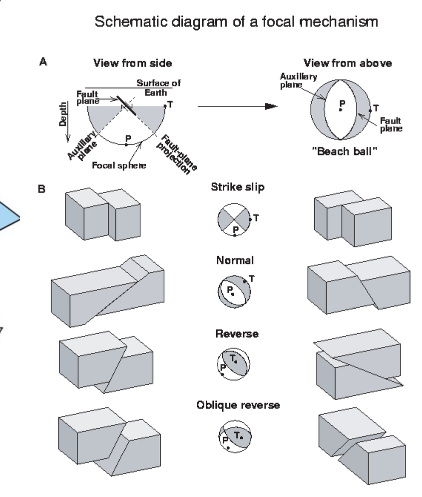
Spatial Skills in the Geosciences

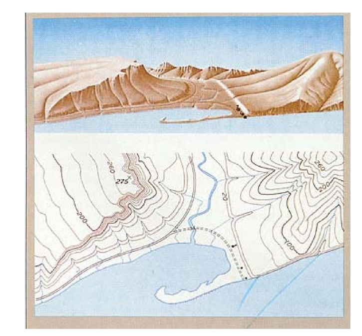
Courses in the geosciences have ambitious goals for teaching students about complex global processes. Instructors use images such as graphs and maps as tools to communicate geologic concepts and relationships. Then, students must mentally translate those graphs and maps to interpret complex processes that vary in space and time. Spatial abilities are used to mentally form, inspect, transform, and interpret images. To facilitate student success in the sciences, it is important to understand the spatial abilities of students and how well they can complete complex visual tasks.



Spatial relations is the ability to mentally rotate an object about its center. In the geosciences, this skill is used to evaluate crystal structures in mineralogy or to determine fault planes using a stereonet.







Spatial orientation is the ability to mentally manipulate or transform an image or spatial pattern into another arrangement. For example, geoscience students must interpret a three-dimensional relationship such as a fault or fold represented on a two-dimensional map.

Data Analysis

To measure changes in student spatial ability, we used pre- and post-test scores and paired T-tests to determine whether improvement in spatial ability was statistically significant. Improvement was considered significant for p value < 0.05. To compare the independent groups, we used one-way analysis of variance (ANOVA) of the mean scores. In addition, we calculated the Hake score for each group, which is a comparison of the improvement by a group, normalized by the maximum possible improvement. For all groups, the study sample includes only students who completed the spatial ability tests both at the beginning and end of the course.

Study Participants

High School

(HSE), students completed seven GIS units which required over 20 hours of instruction in the computer laboratory in addition to time spent finishing the questions as homework.
(HSC), two other high schools served as a control group.

Large-Enrollment Introductory Courses for Non-Science majors

(Geos 218)- Geologic Disasters and Society, students completed four GIS units
(Geos 212)- Oceanography, served as a control group (did not complete any homework or other exercises that included activities designed to develop spatial skills)
- Both lectures include a significant number of maps, animations and other types of visualizations of Earth processes.

Geoscience Majors

(Geos 251)- Introduction to Physical Geology,
(Geos 256)- Computer Applications in Geosciences,
- These courses are the first courses taken as part of a degree in geosciences, thus the data set represents the spatial skills of typical first-year geoscience majors.

Measuring Spatial Skills

Results of Spatial Relations Test

Spatial relations ability, as measured with the Cube Comparison test
- requires the subject to mentally rotate an object about its center
- is timed (3 minutes to complete 21 problems)
- is scored by subtracting the number incorrect from the number correct

	Mean (Pre)	SD	N	Mean (Post)	SD	Change	Hake
HSC	3.8	4.8	139	5.9	5.1	2.1 (p < 0.0001)	.12
HSE	4.3	5.3	94	6.8	5.6	2.5 (p < 0.0001)	.15
Geos 212	6.6	4.1	96	8.1	5.3	1.4 (p < 0.01)	.10
Geos 218	7.1	4.3	78	8.4	4.8	1.3 (p < 0.02)	.09
Geos 251	9.3	4.2	19	12.6	4.6	3.3 (p < 0.004)	.28
Geos 256	6.7	6.0	25	10.6	6.7	4.0 (p < 0.005)	.27

Figure 5. Means and Standard Deviations for Pre- and Post-tests of Spatial Relations

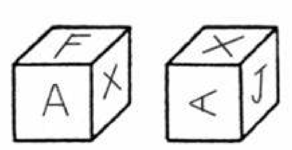
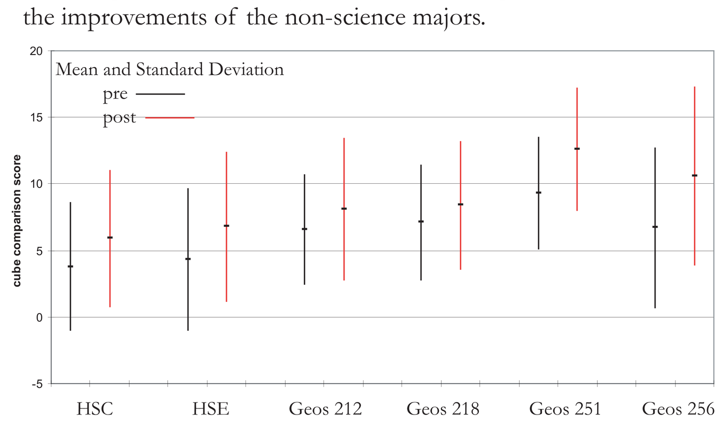
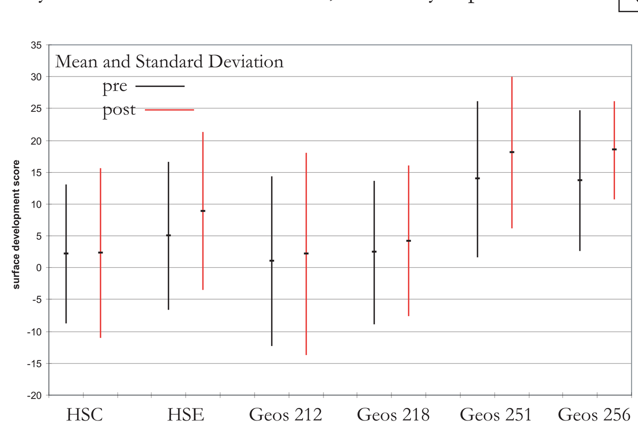


Figure 3. The subject is presented with a pair of cubes, marked with a single letter, number, or symbol on each face. Each face is unique, with no letter or number repeated on a cube. The subject must choose whether the two cubes are the same or different. Analysis of the cubes involves mentally rotating one cube to assess if the cubes match on the visible sides.

- Each set of students (at their respective levels) began the study with statistically the same performance on the pre-test of spatial relations
- Improvement in spatial relations is statistically significant for all groups. Therefore, simple participation in a geoscience course results in an improvement in spatial relations ability.
- We did not observe differences in the spatial relations skills of students that used the GIS from those who did not.
- The improvements by majors on the test of spatial relations, evaluated by the normalized Hake score, are nearly triple the improvements of the non-science majors.





Results of Spatial Orientation Test

Spatial orientation ability, as measured with the Surface Development test
- requires the two-dimensional figure to be mentally folded to align the edges
- is timed (6 minutes to complete 6 problems)
- is scored by subtracting the number incorrect from the number correct

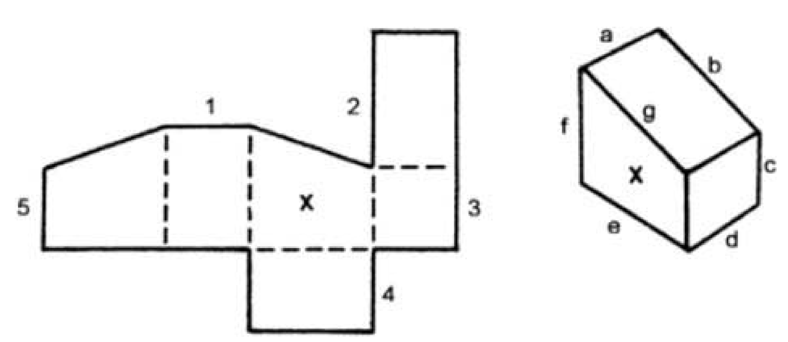


Figure 4. The subject is presented with a two-dimensional unfolded figure and a three-dimensional representation of the folded figure and must identify corresponding edges in the two different drawings. This requires the ability to imagine multiple movements of the unfolded figure.

	Mean (Pre)	SD	N	Mean (Post)	SD	Change	Hake
HSC	2.2	10.8	113	2.3	13.2	0.1 (p < 0.9)	.00
HSE	5.0	11.5	92	8.9	12.3	3.9 (p < 0.0001)	.16
Geos 212	1.0	13.2	91	2.2	15.8	1.3 (p < 0.14)	.04
Geos 218	2.4	11.2	73	4.2	11.7	1.8 (p < 0.08)	.07
Geos 251	13.9	12.1	19	18.1	11.8	4.1 (p < 0.003)	.26
Geos 256	13.7	10.9	19	18.5	7.6	4.5 (p < 0.06)	.29

Figure 6. Means and Standard Deviations for Pre- and Post- Test of Spatial Orientation

- All groups have a very large standard deviation indicating a wide range of ability
- The high school experimental group had a statistically significant improvement, while the control group showed almost no change at all. This difference in improvement could be attributed to the extended use of the GIS curriculum
- There was no statistically significant difference between Geos 212 and Geos 218 (college-level geoscience courses for non-science majors) performance on the pre-test or the post-test
- We were unable to measure an effect of the GIS curriculum on students' spatial relations or spatial orientation ability among students in introductory college courses
- improvements are seen in the spatial orientation scores for Geos 251 and Geos 256 that were not seen in the introductory geoscience courses for non-science majors

Gender Differences

	Mean (Pre)	SD	N	Mean (Post)	SD	Change	Hake
High school Male	4.2	4.7	64	6.0	4.9	1.8 (p < 0.003)	.11
High school Female	3.4	4.9	75	5.7	5.3	2.3 (p < 0.001)	.13
Non-science major Male	7.5	4.4	74	8.6	5.4	1.2 (p < 0.05)	.08
Non-science major Female	6.4	4.0	100	7.9	4.8	1.5 (p < 0.003)	.10
Science major Male	8.5	6.2	24	11.9	6.2	3.3 (p < 0.01)	.27
Science major Female	7.0	4.2	20	11.1	5.7	4.1 (p < 0.002)	.29

Figure 7. Means and Standard Deviations for Tests of Spatial Relations

	Mean (Pre)	SD	N	Mean (Post)	SD	Change	Hake
High School Male	3.7	12.3	50	1.9	14.9	-1.8 (p < 0.27)	-.07
High School Female	1.0	9.5	63	2.6	11.8	1.6 (p < 0.13)	.06
Non-science major Male	2.3	12.7	71	4.2	15.9	1.8 (p < 0.06)	.10
Non-science major Female	1.0	12.1	93	2.3	12.6	1.5 (p < 0.11)	.07
Science major Male	17.9	10.5	20	20.3	9.3	2.4 (p < 0.18)	.20
Science major Female	9.3	11.0	18	16.1	10.2	6.7 (p < 0.002)	.33

Figure 8. Means and Standard Deviations for Tests of Spatial Orientation

- For both the high school students and introductory non-science majors, there is no gender-related statistical difference in the spatial relations or spatial orientation skills in the initial or final tests scores.

- There are observable differences by gender among science majors. Males are starting the courses with a significantly higher ability on both tests; however, female students experience nearly double the improvement of males and have statistically indistinguishable skills from those of males at the end of the semester.

Temporal Changes

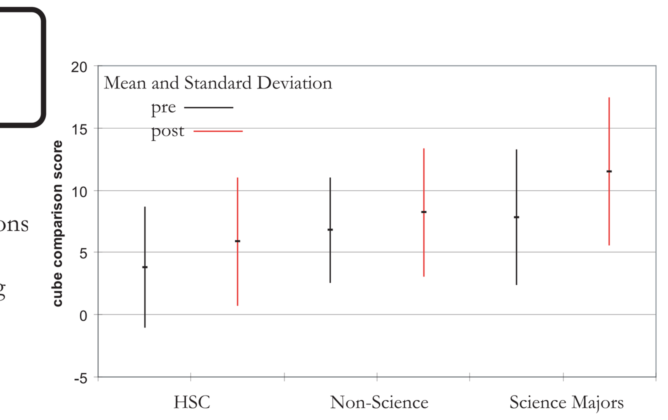


Figure 9. Means and Standard Deviations for Tests of Spatial Relations

- High school students are completing their freshman year with the average spatial relation ability of students entering the University

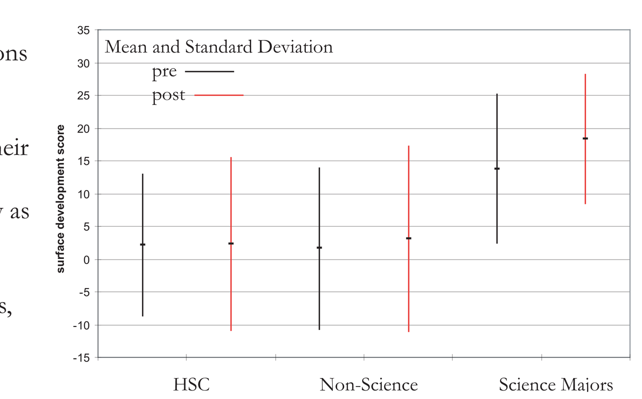
	Mean (Pre)	SD	N	Mean (Post)	SD	Change	Hake
High School (HSC)	3.8	4.8	139	5.9	5.1	2.1 (p < 0.0001)	.12
Non Science Majors (212, 218)	6.8	4.2	174	8.2	5.1	1.4 (p < 0.0001)	.10
Science Majors (251, 256)	7.8	5.4	44	11.5	5.9	3.7 (p < 0.0001)	.28

	Mean (Pre)	SD	N	Mean (Post)	SD	Change	Hake
High School (HSC)	2.2	10.8	113	2.3	13.2	0.1 (p < 0.9)	.00
Non Science Majors (212, 218)	1.6	12.3	164	3.1	14.1	1.5 (p < 0.02)	.05
Science Majors (251, 256)	13.8	11.4	38	18.3	9.8	4.4 (p < 0.002)	.27

Figure 10. Means and Standard Deviations for Tests of Spatial Orientation

- High school students are completing their freshman year studies with the average ability of students entering the University as non-science majors.

- There are significant standard deviations, revealing a wide range of abilities in all groups.



- There is a marked difference in the spatial orientation ability of incoming students depending on whether they are a science major or non-science major, with majors having significantly higher abilities.

Conclusions

All subjects improved their spatial relations ability, indicating that this skill can be improved by simple participation in a geoscience course. Growth in spatial orientation ability occurred both when the students used the GIS curriculum for an extensive period of time (HSE group) and in the courses that had a hands-on weekly laboratory experience (Geos 251, Geos 256). Developing this spatial ability likely requires more interactive learning and manipulation of objects or images than is offered in a typical lecture style learning environment.

Drawing conclusions from human subjects data is complex, correlations can be influenced by other factors related to the course instruction or curriculum materials. In addition, it is important to note that there is a significant standard deviation in all groups. In the introductory courses for non-science majors there are students with very high spatial skills. These are perhaps the students most likely to be recruited as science majors. However, there are also science majors with very low spatial abilities. Due to the prevalence of concepts that require spatial abilities throughout the degree program, identifying early those students that may require additional spatial training could improve retention of science majors.

While there is evidence of self-selection for science majors based on spatial ability, this may be an effect of previous coursework in the sciences. While high scores indicate an aptitude, low scores do not necessarily indicate a lack of aptitude. With proper training and experiences, the potential exists for all students to develop the necessary spatial skills to evaluate science concepts. Integrating coursework that improves spatial abilities at the high school level will have a positive effect on students performance in science and may result in a larger number of students choosing science majors. Finally, the low average performance of students in the high school and introductory college courses suggests that we also evaluate teaching strategies in all courses to ensure that students can interpret and understand the visual imagery used in lectures.