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Developing Transferrable Geospatial Skills in a Liberal Arts Context

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ABSTRACT

Geology education usually takes place within the context of a broader curriculum, but specific synergies between disciplines have rarely been explored or exploited. Here, we have assessed the spatial visualization skills of undergraduate students in a variety of disciplines to determine which are most compatible with a geology curriculum. Spatial abilities are considered one of the most important cognitive skills in the geosciences but there has been little comparative work among disciplines (and particularly non-Science, Technology, Engineering and Mathematics disciplines). Our results demonstrate that geology students had the highest average spatial test scores (a mean of 16.4 out of a possible 20) among the 11 disciplines assessed, and this remained true even after correcting for the effects of gender and grade point average. Both physics and fine arts students also performed well on this assessment. A major implication of our study is that geology students can deliberately enhance their spatial abilities by taking courses in other fields, such as the fine arts, which are known to build those same abilities. In this way, geology curricula may be developed to maximize the benefits of a broad education and thus, ultimately, produce higher-performing geologists. *© 2011 National Association of Geoscience Teachers*. [DOI: 10.5408/1.3580758]

INTRODUCTION

Faced with an Earth that operates on scales so far removed from human experience that much of it cannot be directly observed, geologists must learn to conceptualize the physical world in their minds. For example, the Pacific tectonic plate, whose movement produces earthquakes in California and the volcanoes of Kamchatka, covers over one-quarter of Earth's surface. It is able to float above the asthenosphere thanks to the low density of its constituent minerals, which is determined by their atomic-scale properties. In addition, the rates of many Earth processes—e.g., the filling of sedimentary basins, the evolution of species, orogenies—are too slow to observe their long-term effects. Thus, it is not surprising that geology as a discipline requires substantial spatial thinking skills (Orion et al., 1997; Black, 2005; Kastens and Ishikawa, 2006; Reynolds et al., 2006), which permit geologists to visualize and manipulate objects cognitively rather than tangibly.

Because of its particular importance, spatial thinking is among the most well-studied cognitive skills in the geosciences. These studies have shown that spatial skills are developed even in introductory geology courses (Orion et al., 1997; Titus and Horsman, 2009) and continue to improve through the geology curriculum (Titus and Horsman, 2009). Spatial ability generally translates into academic success, as students with greater spatial skills typically achieve higher grades (Muehlberger and Boyer, 1961; Piburn et al., 2005; Titus and Horsman, 2009), and poor spatial abilities may even be linked to greater earth science misconceptions (Black, 2005). Although spatial skills are often not taught deliberately, they can be improved with practice (Pallrand and Seeber, 1984; Lord, 1985, 1987; Reynolds et al., 2006). Despite this growing body of research on spatial skills in the geosciences, however, there have been few explicit comparisons of how geology compares to other science, technology, engineering, and mathematics (STEM) disciplines, which typically are also strong in spatial skills (Foote, 1981; Pallrand and Seeber, 1984; Russell-Gebbett, 1985; Bodner and Guay, 1997), or whether these same skills are also present in non-science disciplines.

Geology education generally takes place within the context of a broader curriculum, in which students are required to take courses outside of their major discipline to satisfy distribution requirements. This happens most notably at exclusively undergraduate, four-year liberal arts colleges, which tend to emphasize general knowledge and analytical ability rather than a specific set of professional skills. These colleges enroll about 5% of all students but account for about 20% of geoscientists who go on to earn a Ph.D. (data from the National Science Foundation's Survey of Earned Doctorates, 1997-2006, and the National Center for Education Statistics, IPEDS Fall Enrollment 2004). The situation is not unique to liberal arts colleges, as most larger universities also require distribution courses. Thus, broadly educated geoscientists are disproportionately represented in the profession.

Given that geology education emphasizes spatial skills and increasingly takes place within a liberal arts environment, we have assessed spatial skills across a variety of disciplines to determine which might be most synergistic with a geology curriculum. If this cognitive ability is transferrable across disciplines, then that knowledge could help faculty design meaningful geology curricula that include relevant courses from outside the discipline, as well as help students select the highest-impact courses to fulfill their graduation requirements.

METHODS

We administered a spatial skills assessment to 140 students at Juniata College in February and March 2010. Juniata College is a small liberal arts college in central Pennsylvania with an almost entirely residential student population of about 1500. We used the Purdue Visualization of

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Rotations test developed by Bodner and Guay (1997) to test mental rotation ability. Black (2005) demonstrated that scores on this test have a high correlation with those from similar assessment instruments. The directions for the test ask the student to determine how a three-dimensional shape is rotated and to then mentally rotate a second shape in the same manner. Each question had five responses from which to choose. Students were given 10 min to respond to the 20-question test to avoid analytical processing (Bodner and Guay, 1997). In a previous study, Titus and Horsman (2009) used the same assessment instrument to test spatial relationships, in conjunction with two other assessment instruments which measured spatial manipulation and visual penetrative ability. They found that students enrolled in a geology course improved in all three tasks after completing the course suggesting that spatial relation, spatial manipulation, and visual penetrative ability are correlated and can be measured as one cognitive skill. However, strictly speaking, our study only assesses spatial relations, and therefore our results should be considered to apply only to that component of spatial abilities.

We administered the assessment to students enrolled in upper-level courses, on the assumption that any effects of discipline on spatial ability will be the most apparent at this level, after the students had encountered discipline-specific material over the previous few years. Most of the students were in their third (junior) and fourth (senior) year, although several second-year (sophomore) students were also tested. Because each of these courses had prerequisites, regardless of their class year, all students had encountered in-depth material in that discipline for at least a semester prior. We attempted to assess as many disciplines as possible, and particularly sought those that our geology students were most involved in to satisfy their liberal arts distribution requirements. After removing disciplines with fewer than five students, our total sample included 131 students from 11 disciplines: biology, business, chemistry, environmental science, fine arts, geology, history, mathematics, physics, political science, and psychology.

Along with test score and major program of study, we collected basic demographic information from each student including gender, class year, and grade point average (GPA). Gender was collected because studies (e.g., Linn and Peterson, 1985) have shown that on spatial ability tests, males generally outscore females on average. We collected class year and GPA data because academic level and performance may have a strong relationship to spatial skill performance. Because the test was administered in different courses, we also documented what time of day (morning or afternoon) each student took the test.

Analyses were performed using SPSS 17.0. Unless otherwise specified, the alpha level used to determine statistical significance was 0.05.

RESULTS

We observed a significant difference in spatial test scores among disciplines, $F(10, 120) = 2.00$, $p = 0.039$, with an overall mean spatial test score of 13.3 correct out of a possible 20. Geology students had the highest mean spatial test score ($M = 16.4$, $SD = 2.1$), which was statistically significantly higher than the overall mean, $t(7) = 4.1$, $p = 0.004$ (Fig. 1). In general, natural sciences scored higher than social sciences or humanities, with the exception of fine arts students, who were the only non-STEM discipline to score above the overall mean.

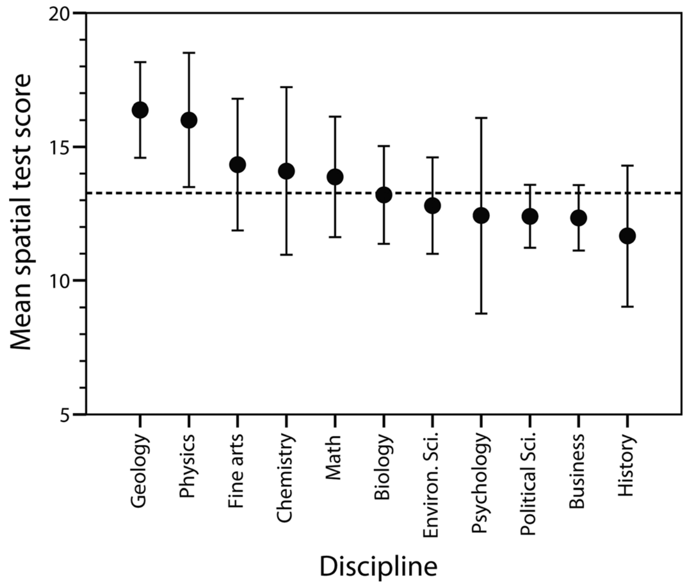

FIGURE 1: Mean spatial test scores and 95% confidence intervals, by discipline.

We also observed a significant difference in scores between genders, $t(129) = -2.4$, $p = 0.02$, with men ($M = 13.9$, $SD = 3.4$, $N = 73$) having higher scores than women ($M = 12.5$, $SD = 3.4$, $N = 58$), as well as a marginally significant positive correlation of score with GPA, $r(129) = 0.17$, $p = 0.05$ [Figs. 2(a) and 2(b)]. The effect of GPA on spatial test score was very small, accounting for only about 3% of the variation. The effect of class year was statistically insignificant, $F(2, 128) = 1.8$, $p = 0.2$, as was the effect of session time, $t(129) = 1.0$, $p = 0.3$ [Figs. 2(c) and 2(d)].

Disciplines also differed significantly in both the proportion of men to women, $\chi^2(10, N = 131) = 23.2$, $p = 0.01$, and in average GPA, $F(10, 120) = 2.2$, $p = 0.02$. This result raised the possibility that the disparity in spatial test scores among disciplines was caused by underlying differences in gender proportion or average GPA, rather than some factor specific to the discipline. We tested this possibility using an analysis of covariance which included spatial test score as the dependent variable, discipline as the independent effect, and gender and GPA as covariates. After accounting for the effects of gender and GPA, the score differences among disciplines were reduced somewhat in significance, to $F(10, 131) = 1.8$, $p = 0.06$. However, the differences remained significant at a less restrictive $\alpha = 0.10$ level, indicating that average spatial test scores likely would have been different among disciplines even if they had the same gender balance and their students had equivalent GPAs. The estimated spatial test scores after controlling for gender and GPA showed little change from the raw means (Fig. 3), and the rank order of the disciplines was preserved in 8 of 11 cases (small changes in rank order were experienced by environmental science and psychology, which increased, and math, which decreased). Geology students had the highest mean spatial test scores even after correction for these confounding influences ($M = 15.9$, $SE = 1.1$).

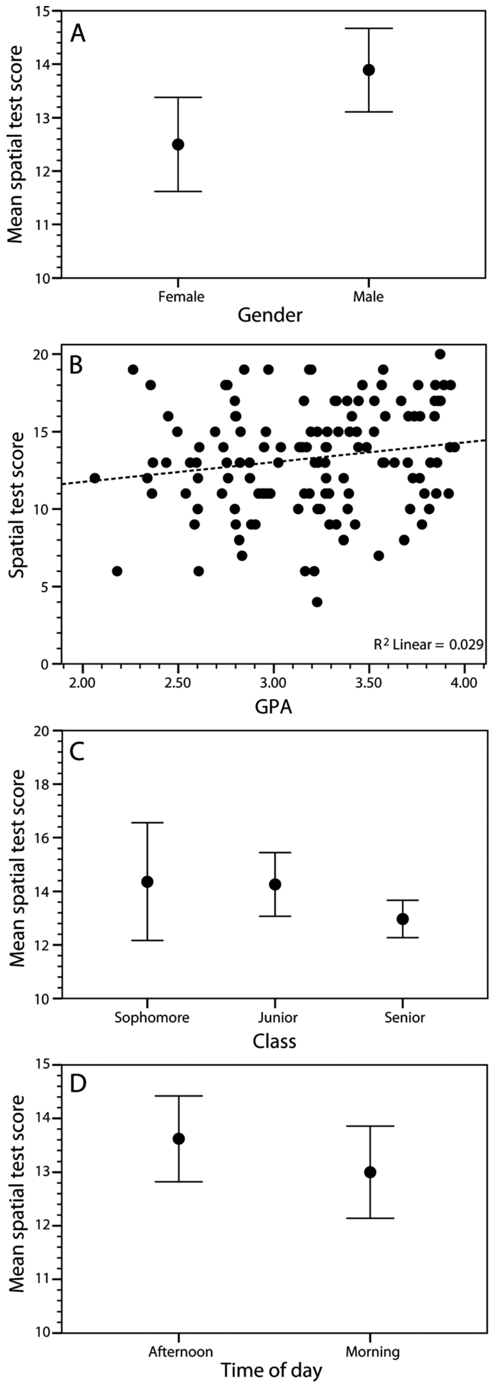

FIGURE 2: Mean spatial test scores by (a) gender, (c) class year, and (d) session time, and (b) the correlation of spatial test score with GPA (grade point average, as calculated on a four-point scale). Error bars indicate 95% confidence intervals.

Differences between the spatial abilities of men and women are often thought of as innate. However, given that spatial abilities can be improved through practice (Pallrand and Seeber, 1984; Lord, 1985, 1987; Reynolds et al., 2006), it is possible that gender differences are acquired if men and women tend to choose different disciplines that emphasize spatial skills to varying degrees. We tested this possibility by examining the difference in performance between men and women within each discipline. We employed a binomial test for this purpose because sample sizes within each discipline were too small for a direct comparison. The observed proportion of disciplines in which men scored higher than women was greater than expected by chance ($p = 0.02$). Our data indicate that gender differences are apparent even when men and women have had the same training.

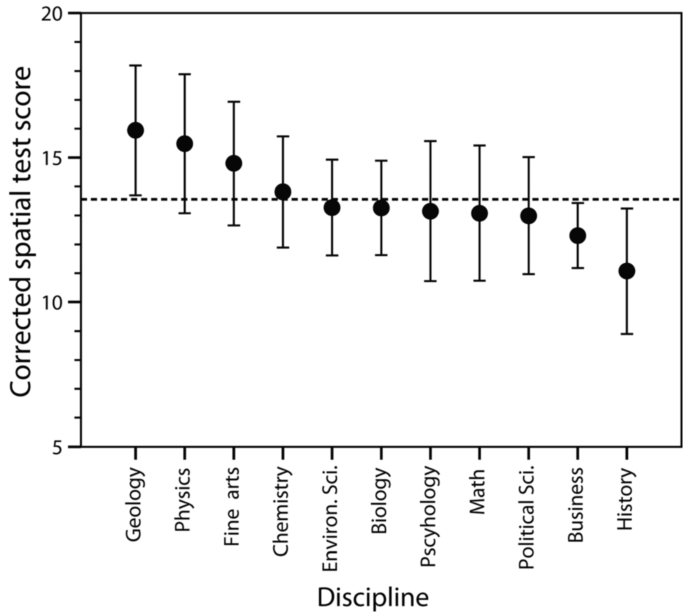

FIGURE 3: Mean spatial test scores and 95% confidence intervals by discipline corrected for the effects of gender and GPA (as calculated on a four-point scale). Values are "estimated marginal means" as calculated by SPSS. Dashed line indicates the grand mean, $M = 13.6$.

DISCUSSION

Consistent with previous studies, our results demonstrate that geology students are particularly adept at spatial thinking. This result remains true even after correcting for variation in gender proportion and GPA. The rank

TABLE 1: Summary of results by discipline.[1]

Discipline	*N*	Mean	Std. Dev.	Max	Min
Accounting, Business, and Economics	32	12.3	3.3	19	4
Biology	15	13.2	3.2	19	6
Chemistry	11	14.1	4.6	20	6
Environmental Science	15	12.8	3.2	18	7
Fine Arts	9	14.3	3.2	19	9
Geology	8	16.4	2.1	19	12
History	9	11.7	3.4	15	6
Mathematics	8	13.9	2.6	18	10
Physics	7	16.0	2.7	19	11
Political Science	10	12.4	1.6	15	10
Psychology	7	12.4	3.9	18	8
Total	131	13.2	3.4	20	4

[1]Full results are available as supplementary online information.

order of disciplines by mean spatial score also aligned closely with our expectations. We found that students in the natural sciences generally scored higher, on average, than students in the social sciences and humanities. A notable exception was fine arts, which had the third highest mean score overall and was statistically indistinguishable from the top two, geology and physics. Although little work has been done on why people in particular disciplines exhibit greater spatial abilities, we note that these disciplines generally require intensive, hands-on laboratory experiences as a normal part of their curriculum.

It is important to note that the results reported here are averages, which by definition summarize variation. While they accurately portray general trends, we caution that they should not be used to predict or assume an individual's performance. For example, a history student may have better spatial skills than a geology student, a female student may outperform a male student, or a student with a low GPA may have well-developed spatial ability. Titus and Horsman (2009) reported that many students achieved high grades in a geology course despite low scores on a mental rotation test. Poor spatial abilities are not an indicator of failure; high spatial abilities are not a guarantee of success.

Different cognitive skills may be developed to varying degrees by different disciplines, depending on their value to that discipline. In fact, we noticed a slight tendency for scores to improve from junior to senior year in disciplines that had higher-than-average mean scores, and for scores to decline from junior and senior year in disciplines that had lower-than-average mean scores. Overall, four of the five highest-scoring disciplines showed improvement over time, while four of the five lowest-scoring disciplines declined over time (one discipline, political science, was excluded because it contained only seniors). This result was not significant using Fisher's Exact test, $p = 0.2$, but it does raise the possibility that spatial abilities may atrophy in disciplines that do not require those skills, just as spatial abilities may be enhanced in disciplines that do. This possibility deserves further study with larger sample sizes.

Most importantly, our results may be applied to curriculum design and course selection. Geology students at nearly all institution types are required to take courses outside their major program of study, and this is particularly true at liberal arts colleges. At Juniata College, for example, all students are required to take at least two courses in each of five areas (and six of these ten must be upper-level courses) to satisfy their distribution requirements. Because spatial skills can be improved with practice (e.g., Reynolds et al., 2006) and such skills are emphasized in particular disciplines, our results suggest that a liberal arts curriculum can be used to geologists' advantage by identifying courses with transferrable geospatial skills and encouraging students to enroll in them. This reasoning also works in the reverse: geology and physics in particular would benefit fine arts students, for example, who need to take a natural science course to satisfy their graduation requirements. Alternatively, we can imagine a situation in which students should be discouraged from taking courses that build the same cognitive skills as their major courses, so that they are exposed to different ways of thinking or methods of analysis. The major implication of our study is that there is significant overlap in spatial skills among certain (but not all) disciplines, and that this fact has, to our knowledge, not been exploited to the advantage of geologists. As the distribution of other cognitive skills among disciplines becomes increasingly well known, we foresee a future in which geology programs can include advice on which courses outside their department will enhance their students' education, thus ultimately strengthening the field.

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APPENDIX

Supplementary Online Data

We have included our raw data in this Appendix (see **EPAPS raw data**). The variables are as follows:

- **Test code**, an anonymous, unique test identifier;
- **Session**, the date and time the test was administered;
- **Score**, the raw score on the spatial assessment, out of a maximum of 20 points;
- **Gender**;
- **Program**, the major field of study of the participant (BA.CM = Communications, BA.EB & BS.EB = Accounting, Business, and Economics; BA.EN = English; BA.ES & BS.ES = Environmental Science and Studies; BA.FA = Fine arts; BA.HS = History; BA.LA = Liberal arts; BA.PL = Philosophy; BA.PS = Political Science; BA.SO = Sociology and Anthropology; BS.BI = Biology; BS.CH = Chemistry; BS.CS = Computer Science; BS.GL = Geology; BS.MA = Mathematics; BS.PC = Physics; BS.PY = Psychology; ND = Non-degree; PD.BA = Partner degree, joint degree with another, usually international, institution);
- **GPA**, the grade point average on a four-point scale; and
- **Class** (SO = sophomore; JR = junior; SR = senior).

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See EPAPS supplementary material at http://dx.doi.org/DOI:10.5408/1.3580758.