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ABSTRACT

Students in science and non-science departments of the State University College, Buffalo, were given the Survey of Object Visualization, a test designed to measure aptitude to visualize objects when disassembled and in various positions. Science majors scored significantly higher than non-science students. Within the science group, different bands of scores were associated with the student's major. Physics students tended to score highest, followed, in order, by geoscientists, biologists and chemists. There was a high correlation between Survey of Object Visualization and science grades. The results suggest that three dimensional conceptualization tests could be included in test batteries given to prospective college science students to facilitate counseling. (AL)

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SPATIAL COGNITION, A SUCCESS PROGNOSTICATOR IN COLLEGE SCIENCE COURSES

Early recognition of scientific aptitude possible by testing student spatial conceptualization ability.

by

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Abstract. The ability to conceptualize clearly three dimensional models from two dimensional representations appears to be the critical factor in the screening of science-oriented from nonscience-oriented college students. Even among scientists spatial cognition appears to be present at different levels, with physicists possessing the highest degree of space conceptualization, and chemists, the lowest. An important finding is the realization of how inept some nonscience students are in visualizing three dimensional models from printed illustrations. Serious thought must be given to the development of new techniques for the teaching of science to these individuals.

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Findings of a recent study conducted at State University College, Buffalo, New York may reduce the risk factor in the selection of college science majors and graduate students wishing to pursue higher degrees in science.

Counselors, as well as graduate faculty committees, are frequently confronted with critical judgments regarding the advisability of accepting or rejecting applicants in search of science degrees. The decision is more complex in science than in other fields because there is no clear understanding of elements, other than intelligence and motivation, required for success in science courses and research. Thus, the problem of advisement takes on an added dimension when college students consider careers in science.

Must a science student possess special aptitudes beyond those required of liberal arts students in such fields as history, literature, and social sciences? Is a satisfactory grade on a college entrance test or the graduate record examination an indicator of success in a science program? Many special fields have recognized that further testing is necessary in the selection of students. Art departments require, in addition to the usual entrance requirements, the student present an art portfolio indicative of his artistic potential. Music departments require special testing for tone discrimination and rhythm patterns. Dental schools test for dexterity.

Such precautionary measures as those mentioned above have not been employed in the screening of science students. This is not due to negligence on the part of science educators but, most likely, the consequence of the absence of a suitable instrument for such testing. The test instrument has not been developed since it is not known whether any skills or aptitudes are required for a successful career in science. There is, however, evidence that a student who succeeds in science differs somewhat from one who fails in a science course. The difference is not always due to differences in intelligence or motivation but, frequently, to the ease in comprehending science concepts.

Based on many years of observation of science students, the authors hypothesize that this difference in ability among students to comprehend science principles is, to a large extent, caused by the ability of some students to conceptualize three dimensional models clearly.

This study reports the relationship of the special faculty of spatial cognition to the prognostication of achievement in college science courses, given that the students have a proper level of intelligence, prior scholastic aptitude, and the desire to become involved in a science career.

Spatial conceptualization was selected as the special skill to be investigated because science students are constantly subjected to diagrams, usually of two dimensional representations of three dimensional models, or two dimensional abstracts of landforms, as in contour mapping, to be interpreted in three dimensions. The need for three dimensional conceptualization is necessary for the comprehension of wave energy transmission, chemical bonding, fields of force, structure of the atom, X-ray diffraction patterns, DNA, cell division, and countless other concepts and phenomena found in every branch of science. Three dimensional conceptualization is essential for the understanding of scientific principles ranging from one as simple as the circulation of blood in the human body to that involving the complexities of quantum mechanics.

Interest in spatial cognition as a success predictor in college course achievement was first investigated by the Council of Dental Education of the American Dental Association. The test instrument, Survey of Object Visualization (SOV) (1), was included in its aptitude testing battery.

Peterson (2) found a correlation coefficient of .44 between scores on the Survey of Object Visualization and freshman technic grades. Some of the other predictors in the battery included predental grades, quantitative intelligence, linguistic intelligence, reading in science English comprehension, and carving dexterity. The correlation coefficient between freshman technic grades and SOV scores was found to be higher than correlations between these grades and the scores on other predictors in the battery.

Layton (3) performed a similar study using the testing bettery of the Council of Dental Education and reported a correlation coefficient of .49 between SOV scores of 81 students and their four-year honor points. This correlation coefficient was the highest of all tests in the battery.

A recent study by Martin (4) employing analysis of covariance techniques to control individual differences in scholastic aptitude and academic ability, investigated the spatial visualization abilities of prospective and experienced mathematics teachers as compared to students completing curricula in other areas including science. The findings report that prospective science teachers score significantly higher in spatial visualization than do prospective teachers in elementary mathematics, social studies, and English. Martin reports no relationship between scholastic aptitude and spatial visualization ability. The latter observation is in agreement with the findings of Thurstone (5) and Super (6).

The investigation by Roe (7) of 64 eminent scientists reveals that the faculty of spatial cognition is prominent among highly successful scientists. All of her subjects received worldwide recognition in terms of honorary degrees, prizes, and other awards for great achievement. The Educational Testing Service of Princeton University prepared a special intelligence measurement instrument for use in the study. Included in this battery was a 24 item spatial conceptualization test. The analysis of the data based on scores made in the spatial test is shown in TABLE 1. The tabulation shows that not only are scientists capable of a high level of three dimensional conceptualization, but the degree of spatial conceptualization varies in each science discipline, with the theoretical physicists highest and anthropologists lowest.

TABLE 1

SPATIAL COGNITION

OF EMINENT SCIENTISTS

Field	Number	Mean	Range
Biologists	19	9.4	3-20
Exper. physicists	7	11.7	3-22
Theoret. physicists	11	13.8	5-19
Psychologists	14	11.3	5-19
Anthropologists	8	8.2	3-22
Total	59*	10.9	3-22
Approx. I.Q. Equival.		140.0	123-164

*There was no explanation in the report for the difference in the total number. Evidently 5 of the scientists were not available when the spatial cognition test was administered.

Roe's findings suggested the testing of a second hypothesis determining whether different levels of spatial cognition appear among college students majoring in the various fields of science. Should the findings indicate that certain threshold levels exist, it would further aid the counseling of students.

Method

The investigators in the present study began collecting data December 1966 at State University College, Buffalo, New York, and continued the study through the spring semester of 1970.

The investigation tested three null hypotheses:

1. There is no difference in three dimensional conceptualization between science and nonscience majors,
2. There are no differences in three dimensional conceptualization among majors in various science disciplines, and
3. There is no correlation between three dimensional conceptualization ability and quality points earned by science majors in college science courses they have taken.

The confidence level set for the rejection of the null hypothesis was $\alpha = .05$.

At the rejection of the hypothesis of equal means, the alternate hypotheses tested the importance of spatial cognition in the three problem situations selected.

Subjects selected included science majors in the departments of Physics, Biology, Geoscience, and Chemistry. Nonscience-oriented students were selected from the Elementary Education Division, the Exceptional Education Division, and liberal arts majors. The investigation expanded later to include students from the Department of Mathematics and the Art Division at State University College.

Initially, students were administered two dimensional and three dimensional visualization tests (8). Preliminary comparisons of test results indicated that the three dimensional test was more sensitive in discriminating differences between science and nonscience students.

Following the initial testing, all subjects in the study were administered the Survey of Object Visualization (SOV) devised by Daniel R. Miller. This test is designed to measure the examinee's aptitude to visualize an object when it is disassembled and in various positions.

Findings

Statistical treatment of test scores produced the results shown in TABLES 2, 3, 4, 5, 6 and 7.

Analysis of the Survey of Object Visualization scores (TABLE 2) indicates that science majors score significantly higher than nonscience students. Included in the sample were 57 nonscience-oriented students (9) and 89 science majors. The mean of the nonscience group was 24.49 with a standard deviation of 9.99. The science majors had a mean of 29.63 and a standard deviation of 8.55. The F-value of 10.99 exceeds the critical point of 3.88 required for the rejection of the null hypothesis. These results indicate that science majors possess the ability to conceptualize three dimensionally at a much higher level than do students in nonscience fields of study.

TABLE 2

ANALYSIS OF VARIANCE

SOV SCORES OF NONSCIENCE

AND SCIENCE MAJORS

Source of Variation	df	M.S.	F	P	Required F*	Decision
Between groups	1	917.27	10.99	<.05	3.88	Reject
Within groups	144	83.44				

*F-value required to reject null hypothesis at .05 level.

To test whether different levels of spatial cognition exist among the science majors the analysis of variance was repeated but with the science group subdivided into the four major fields of study. Results of the analysis appears in TABLE 3.

TABLE 3

ANALYSIS OF VARIANCE

SOV SCORES OF NONSCIENCE

STUDENTS COMPARED TO

PHYSICS, BIOLOGY, CHEMISTRY

AND GEOSCIENCE STUDENTS

Source of Variation	df	M.S.	F	P	Required F*	Decision
Between groups	4	544.67	7.14	<.05	3.72	Reject
Within groups	141	76.27				

*F-value required to reject null hypothesis at .05 level.

The F-value of 7.14 exceeds the critical point of 3.72 required for rejection of the null hypothesis supporting the hypothesis of the superiority of science students over their nonscience-oriented classmates in spatial cognition.

An examination of the means and standard deviations in TABLE 4 shows that the science majors do differ in degrees of competence in spatial cognition.

TABLE 4

LEVELS OF SPATIAL COMPETENCE

AMONG TREATMENT GROUPS

Group	Number	Mean	S.D.
Nonscience	57	24.49	9.99
Physics	17	37.18	5.45
Biology	44	27.96	7.53
Chemistry	17	26.47	10.07
Geoscience	11	29.55	7.95

The pattern appearing in TABLE 4 is substantially in agreement with the findings of Roe shown in TABLE 2. The physics majors have greater capacity for spatial cognition than do students in other science fields. The means range from a high of 37.18 in physics to a low of 26.47 in chemistry. It should be noted, however, that all science groups tested had a higher mean than that of the nonscience group.

A comparison of each science group was made with the scores of the nonscience group using the t-statistic to test significance. The results are tabulated in TABLE 5.

The physics, biology, and geoscience majors scored significantly higher than the nonscience-oriented students. Spatial cognition is extremely strong among physics students.

Although the chemistry majors' scores were higher than those of the nonscience group (TABLE 4), the difference was not statistically significant at the .05 level of confidence.

Data tabulated in TABLES 4 and 5 shows that bands of spatial cognition appear and that each science discipline requires a different level of competence for success in that field.

TABLE 5

COMPARISON OF NONSCIENCE GROUP

WITH EACH SCIENCE SUBGROUP

USING T-STATISTIC

Science Subgroup	df	T-Value	Required T*	Significance Level
Physics	53	6.79	1.67	.0001
Biology	101	1.99	1.66	.025
Chemistry	27	0.71	1.70	N.S.**
Geoscience	18	1.85	1.73	.05

*Critical point at .05 level of confidence.

**Difference between means not significant.

To test the third null hypothesis of no correlation between spatial cognition and quality points earned in science courses, the authors selected the science majors tested in 1966. With the cooperation of the Registrar's Office, the science grades of these students covering a period of approximately three years were recorded and then converted into quality points. The Pearson Product-Moment correlation coefficient was computed comparing the scores made on the SOV test and the quality points earned in science. The resulting correlation coefficient was r = .51. Testing the significance of the correlation, t = 4.6, showing the correlation to be significant at the .0001 level of confidence. The high level of significance of the correlation between quality points ans SOV scores underscores the predictive potential of spatial cognition tests.

Spatial Cognition in Mathematics and Art Students

To test whether spatial cognition is prominent in special fields other than science, the authors administered the SOV test to mathematics and art majors. A comparison was made between each of these groups and the nonscience group. The results of F-tests made are shown in TABLES 6 and 7.

The mean score of the mathematics majors was 32.37 with a standard deviation of 7.12. The mean of the nonscience-oriented students, as shown in TABLE 4, was 24.49 with a standard deviation of 9.99. The F-value of 10.07 (TABLE 6) far surpasses the 3.98 required for the rejection of the hypothesis of equal means. It should be noted that spatial conceptualization ability of mathematics majors compares favorably with that of science majors. Only the physics group exceeded the scores of the mathematics students (TABLE 4).

TABLE 6

ANALYSIS OF VARIANCE

SOV SCORES OF NONSCIENCE STUDENTS

AND MATHEMATICS MAJORS

Source of Variation	df	M.S.	F	P	Required F*	Decision
Between groups	1	884.22	10.07	<.05	3.98	Reject
Within groups	74	87.79				

*F-value required for the rejection of the null hypothesis at the .05 level of confidence.

Similar findings were uncovered when comparing the SOV scores of the nonscience group and scores of art majors (TABLE 7).

TABLE 7

ANALYSIS OF VARIANCE

SOV SCORES OF NONSCIENCE STUDENTS

AND ART MAJORS

Source of Variation	df	M.S.	F	P	Required F*	Decision
Between groups	1	491.43	5.80	<.05	3.96	Reject
Within groups	83	84.69				

*F-value required for the rejection of the null hypothesis at the .05 level of confidence.

The mean of the art group was 29.61 with a standard deviation of 7.32. As in the case of the mathematics group, spatial conceptualization of the art majors is surpassed only by the physics majors (TABLE 4).

Conclusions

Findings in the test of the first hypothesis show there is strong evidence that science majors differ from nonscience-oriented students in three dimensional conceptualization. Only in the case of the chemistry majors was a significant difference in the means not found. The means in all science fields, however, were higher than the mean of the nonscience group.

One can only speculate on reasons why students with limited abilities in conceptualizing three dimensional models selected the field of chemistry. It is possible that the students tested were exposed to chemistry instruction based on the empirical approach. Chemistry students exposed to molecular models and theoretical approach to the understanding of the nature of chemical bonding, perhaps, would have scored higher. This does not imply that spatial cognition is a trainable skill. The findings of Martin, Thurstone, and Super, which were mentioned earlier, refute this. Students with limited ability in spatial cognition would not select chemistry as a major field if conceptualization of complex chemical models was required in chemistry courses.

In testing the second hypothesis, findings support the alternate hypothesis that the levels of ability of three dimensional conceptualization differ among the sciences with physicists showing the highest ability and chemists, the lowest.

A test of the third hypothesis indicates strongly that a high correlation exists between three dimensional conceptualization and successful grades in college science courses.

Significance of these findings to the counseling of college students is evident. Three dimensional conceptualization tests should be included in any battery of tests administered to college students contemplating careers in science. Not only can these students be counseled as to their probability of success in science, but they can be directed towards the science field in which they can best perform.

Although the findings did show that mathematics and art majors possess a high degree of three dimensional conceptualization, this should not lessen the predictive abilities of the spatial cognition tests. The relationship of mathematics to science has long been accepted, and there is little danger of a potential art student being counseled into a science program. The primary interest of the student will act as an effective safeguard.

A surprising outcome of this study was the realization of how inept some nonscience-oriented students are in visualizing three dimensional models from printed illustrations. The SOV scores of nonscience students ranged from a few good visualizers, through those of mediocre ability, down to those who might be described as non-visualizers. The science textbook writer who constructs a good diagram thinks he has satisfactorily explained some science principle. The science teacher does not realize how little these textbook diagrams, and those of his own design, mean to many students. These students are by no means stupid, nor do they lack the desire to learn science. They seem incapable of reconstructing in their minds three dimensional models of two dimensional illustrations. This lack of ability in spatial cognition may well explain the fear and hatred of science held by many students majoring in the Humanities.

References and Notes

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7. A. Roe, Sci. Amer. 187, 21 (1952).

8. The two dimensional test used in the preliminary testing was Survey of Space Relations Ability-Form A, designed by H. W. Case and F. Ruch. The three dimensional test was the Survey of Object Visualization mentioned in (1). Both tests are published by California Test Bureau, Los Angeles, Calif.

9. These 57 nonscience-oriented students were elementary education, exceptional education, and liberal arts majors. No art or mathematics majors were included.