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ABSTRACT

Two experiments were conducted to assess the performance of freshmen chemistry students with poor spatial visualization skills. In the first experiment, 31 chemistry students with academically deficient backgrounds completed a diagnostic test of their ability to visualize and interpret pictorial representations of simple molecular structures. At the end of their first semester of chemistry in a special academic support program, it was found that the 19 chemistry students who had failed the diagnostic test underachieved significantly as a group compared to the other 12 chemistry students, while no differences occurred between the two groups on an English language proficiency test. This finding was confirmed with 93 students enrolled in the traditional first year chemistry course, where students who failed the diagnostic molecular structure test underachieved consistently as a group, relative to their spatially able peers. (JDD)

STUDENTS' VISUAL LEARNING DISABILITIES AND UNDER-ACHIEVEMENT IN SELECTED SCIENCE SUBJECTS

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A B S T R A C T

From 1980 to 1986 the spatial visualization abilities of a total of 1 600 students at the University of Cape Town have been monitored in relation to their academic performances in a variety of scientific disciplines. Students with poor 3D perceptual skills tend to underachieve significantly in chemistry, anatomy, astronomy and engineering drawing. This paper focusses on the most recent findings with first year chemistry students enrolled in a special Academic Support Programme in 1986, and in the normal chemistry stream.

On entrance to the Programme, 31 chemistry students with academically deficient backgrounds attempted a 40-item refined and purified diagnostic test of ability to visualize and interpret pictorial representations of simple molecular structures (VPMS). At the end of the first semester it was found that the 19 chemistry students who had failed the diagnostic VPMS at the beginning of the year underachieved significantly as a group (by about 15%, $p < 0.01$) compared to the 12 chemistry students in the Academic Support Programme who had passed the VPMS. On the other hand, no differences occurred between the spatially able and the spatially weak chemistry students on a standardized diagnostic one-hour English Language Proficiency Test (ELPT). It appears that students' deficiencies in the three-dimensional perceptual interpretation of simple molecules is associated with significant underachievement in formal chemistry examinations at the University of Cape Town.

This finding was confirmed with 93 university students enrolled in the traditional first year Chemistry I lecture course in 1986. Science students who failed the VPMS underachieved consistently as a group (by between 10% and 18%) on chemistry tests and examinations throughout the academic year, relative to their spatially able peers.

Since all students who passed the diagnostic VPMS subsequently passed well virtually all class tests and examinations in first year chemistry, it is recommended that the VPMS be used in an academic support programme to suggest the early promotion of previously underestimated chemistry students into the normal lecture stream.

Introduction

Many researchers have recognized that spatial visualization plays an important role in the learning of science. Apparently the ability to perceive, retain and mentally manipulate objects contributes to successful performance in a wide range of scientific/analytic disciplines. This assumption has been substantiated by many investigations which correlate achievement on pencil and paper tests of spatial ability with academic attainment in science courses.

The present study originated with an incidental observation by a lecturer in astronomy at the University of Cape Town. He articulated his concern that many second year students are unable to visualize and calculate stellar positions in three dimensions given two-dimensional blackboard representations. Another lecturer (in anatomy) concurred that each year certain medical students appear to have poor morphological appreciation. Whether this could be severe enough to cause outright academic failure was unknown. It was also suspected that training in anatomy would help to improve spatial ability.

Most instructors of chemistry recognize the importance of spatial visualization skills in the achievement of chemistry students, e.g. Small & Morton (1983); Baker & Talley (1974); Seddon & Tariq (1982); Eniaiyeju (1981); Hyman (1982); and Seddon & Shubber (1985).

Eley (1977:62) has suggested that different topic areas in the natural sciences may be differentially dependent upon spatial abilities, and believes it would be worthwhile to engage in detailed task analyses of these different topic areas to determine which among them seem most, or least, dependent on some minimal proficiency in spatial abilities. He concluded by suggesting that it would also seem worthwhile to research the degree to which spatial abilities are trainable.

According to Just (1979:1) much is unknown about the exact role of spatial ability in scientific cognitive processes. There is evidence that while high spatial abilities may be an overall predictor of success in science, they are not necessary and sufficient conditions for success in all science courses (Witkin,1977; Poole & Stanley, 1972).

Siemankowski & MacKnight (1971:23) found that successful college majors in science, mathematics and art performed significantly better on tests of spatial visualization than did non-majors. They also found that successful college physics majors have excellent three dimensional conceptualization, better than that of any other science, mathematics or art group, while non-science-orientated students were surprisingly inept in this area. This is important because it suggests the possibility of using spatial tests as diagnostic instruments for the early identification of certain science students who might benefit from specialized supplementary tuition. It also suggests that either spatial ability develops with increasing exposure to science, mathematics and art at university level, or that these courses tend to discriminate against students with spatial visualization which remains inadequate or weak.

Brinkman (1966:178-184) demonstrated that spatial abilities are by no means "fixed", and that suitable remedial work can be effective. On the other hand, Smith (1964:166), the Cambridge Report (1969), and Hill (1970:27), report that spatial abilities do not increase greatly beyond the age of about 15 years. Clarity is needed on this important issue.

Previous studies in specific scientific disciplines

A number of investigations have already been carried out on the spatial abilities of tertiary students and professionals in medicine, dentistry, astronomy, engineering and chemistry.

In an unpublished paper, Goodenough, et al. (1977) investigated the relationship between scores on the Embedded Figures Test and specialization in the medical profession. Based on their scores on the spatial test, the medical specialists were classed from most field dependent to most field independent. Rank ordered from radiology to surgery, internal medicine and psychiatry, the differences between surgery and psychiatry were significant at the 0.05 level. The authors suggest that long range prediction about medical career development can be made with some degree of accuracy from knowlege of an individual's cognitive style.

Just (1979) has recently investigated the relationship between spatial reasoning ability and achievement in a dental school curriculum. He reports that all of the following subjects have a common factor with spatial reasoning ability : orthodontics, endodontics, operative dentistry and dental school grades, as well as overall academic success on the average score in all the scientific disciplines (page 34). In other words, the courses which are most closely related to the actual practice of dentistry, as opposed to courses which represent the scientific and sub-structure of the discipline, tend to require visualization abilities. He concludes, "If one were interested in establishing a criterion for predicting successful completion of higher level dental courses, spatial reasoning would be the primary factor". (Page 123)

In an investigation into the reasoning ability of college astronomy students, Schatz (1978) found that approximately 30% of the students were unable to use proportions correctly. He concluded that many individuals were expected to experience problems of a spatial/relational nature when plotting or interpreting graphs such as the Hertzsprung-Russell diagram of stellar evolution or the Hubble relationship. He also found that 37% of his college astronomy students could not determine the correct phases of the moons of Mars when observing a physical model removed from their own frame of reference. He questioned strongly whether individuals who experience this difficulty can understand the elaborate figures given to most textbooks to explain spatial concepts such as the phases of the moon, and the seasons.

In a study with college astronomy students, Kelsey (1980) found that the majority of students do not have, and cannot use, the mental structures required to understand the projective spatial relationships involved in astronomical concepts. She concluded that many teaching materials and classroom presentations may be inappropriate for college astronomy students.

Sonntag (1981) showed that the spatial orientation ability of university science students is a factor that should be considered when designing instructional techniques for classes learning positional astronomy. Students who were placed in the high spatial orientation ability group favoured the classroom teaching method, whereas the low and medium spatial orientation ability groups performed better on the researcher-constructed Positional Astronomy Achievement Post-test if they were in the planetarium or planetarium/classroom-celestial globe groups.

One of the earliest studies conducted with engineering students at college level was by Stuit & Lapp (1941). A high correlation between scores made on the Minnesota Paper Form Board Test of visualization, and success in both engineering drawing and mathematics was noted, but the correlation with success in physics was not significant.

Blade & Watson (1955) administered two tests of spatial orientation to a group of students entering college. The tests were then readministered after the freshman year. They found that among engineering students there were significant differences in spatial test results between the students with the highest grades and students with the lowest grades (after freshman year). Comparing the pre- (upon entry) and post- (after freshman year) spatial test results they report that engineering students had a significantly greater gain than non-engineering students. This is tentatively attributed to a spatial training effect associated with studies in engineering.

Marsicano (1975) evaluated tests which can be used for predicting academic success in engineering technology at Pennsylvania State University. He concluded that the traditional combination of high school results and verbal and mathematical scholastic aptitude tests can be improved by including spatial perception and abstract reasoning tests in the predictive battery.

In an investigation into the results of a first course in engineering drawing at the University of the Witwatersrand, Taylor (1980) used step-wise multiple regression equations to establish that the best combination of predictors in his study consisted of a test of deductive reasoning together with tests of three dimensional spatial ability.

In Taylor's second report (1983) mention is made of the fact that a large percentage of end of year failures in engineering drawing and design obtained lower scores on the three dimensional BLOX TESTS when the time allowed was decreased.

The background to the present investigation should be seen in the context of the findings of studies such as these.

Cooper & Shepard (1973:172) conclude pertinently when they write "Evidently we still have a way to go before we achieve an adequate characterization of mental images and of mental operations upon mental images".

Delimitation of the problem

Although the term "spatial" may apply to objects and concepts in one, two or three dimensions, this investigation is confined almost exclusively to students' visualization in three dimensions.

It is also primarily concerned with valid and reliable methods of identification, rather than methods of remediation of spatial problems. Its chief focus is on the performance of grossly spatially handicapped students who are in danger of failing spatially-orientated courses, despite their satisfactory non-spatial academic achievement in related studies.

The present investigation is limited, in the main, to the years 1980-86, and to the studies carried out on four populations of second year anatomy students, three populations of second year astronomy students, two populations of first year engineering students and two populations of first year chemistry students, all at the University of Cape Town. It is not a cross-cultural study, nor is it directly concerned with the specific influence of such variables as sex, race, IQ, attitude and motivation on spatial academic achievement. The great majority of students involved in the study are of European origin.

The importance of innovative technique in solving the problem.

According to Handler (1976:7008-A), "sound information about ways to develop and to evaluate spatial visualization ability is lacking. The processes used by students in solving complex three dimensional visualization problems have not been well documented". It appears that the creation and evaluation of new experimental techniques in the current investigation is warranted.

The first innovation in the present study is the intentional attempt to hold as constant as possible several important variables (age, status, intelligence and level of previous academic achievement) whilst attempting to measure the possible influence of the variable "spatial ability" on the subsequent scholastic performance of several populations of freshman medical students, most of whom are 20 years old, virtually all of whom have passed the Matriculation examination with "A" averages (that is, more than 80%), and all of whom have been keenly selected for each year of intake from among some 800 applicants.

The second innovation is the recognition and utilization of the fact that individual test and examination questions in certain university science courses (for example, anatomy, astronomy, surveying and crystallography) can usually be separated dichotomously into items whose answers either depend on effective three dimensional visualization or are essentially non-spatial in nature. To illustrate this point, examples of spatial and non-spatial multiple choice questions in anatomy from the University of Cape Town 1980 final examination paper are given in Appendix 1. By judiciously monitoring students' spatial and non-spatial achievements as separate variables directly within the context of the particular academic discipline being taught, it is suggested that a more valid documentation of students' spatial progress can be obtained than merely by the repetitious use of geometric batteries of spatial tests throughout the academic year.

When this innovative technique is applied to students of anatomy, a distinctive pattern begins to emerge. Table 1 records the actual examination results of typical candidates A, B and C who appear to manifest a serious and persistent spatial disability. It is not until the performances of such students are separated into spatial and non-spatial categories, as in Table 1, however, that the trends of the individual students - which would otherwise be lost in the conventional class test statistics - begin to emerge clearly and convincingly.

This effective technique is a natural development and refinement of the experimental strategy adopted by Schonberger (1976) in an investigation into the mathematical problem solving abilities of junior high school pupils. She carefully selected mathematical tasks to make three sub-tests of problems differing in amount of spatial or geometric content.

Clarification of terms

Spatial Ability. For the purpose of this investigation, spatial ability is defined as the ability to perceive, retain and recognise (or reproduce) three dimensional representations of objects in their correct proportions when they are rotated in space, translated, juxtapositioned, projected, sectioned, re-assembled, inverted, re-orientated or verbally described.

Geometric Spatial Proficiency depends on a particular knowledge of the names and shapes of common geometric (as distinct from anatomical) objects.

Anatomical Spatial Proficiency depends on a particular knowledge of the names and three-dimensional properties, characteristics and relative positions of the various tissues, organs and systems in the human body.

Non-spatial Anatomical Proficiency. Since approximately half of the examining in anatomy at the University of Cape Town requires an element of spatial visualization, and the remainder is non-spatial in nature, a distinction must be made between spatial anatomical performance and non-spatial anatomical performance by medical students.

Astronomical Spatial Proficiency depends on a knowledge of the names, patterns and relative positions, orientations and motions of heavenly bodies, with particular reference to positions and rotations within the setting of spherical geometry.

Non-spatial Astronomical Proficiency is the ability to remember and understand factual astronomical data that is independent of position in space, (for example, the temperatures and chemical compositions of designated stars).

Hypotheses

1. That under-achievement in university anatomy, astronomy, chemistry and engineering drawing will be significantly related to performance scores on paper and pencil tests of geometric spatial ability.

2. That spatial ability will be acquired by a majority of spatially weak students during the course of their mainstream studies in science, but that these spatially disadvantaged students will attain spatial mastery at widely differing rates. A small minority will remain permanently spatially disadvantaged.

3. That the predictive validity of paper and pencil tests of spatial ability will decrease significantly with increasing time, as spatially inept students who commence courses of science become more spatially competent during their year of studies.

4. That a subject-based spatial test constructed within a given scientific discipline will be a significantly better predictor of achievement within that discipline than a merely geometrically-based battery of spatial exercises.

5. That a subject-based spatial test constructed within a given scientific discipline will be a significantly better predictor of achievement within that discipline than a subject-based non-spatial test.

6. That chemistry students who fail a diagnostic test of ability to visualize and interpret pictorial representations of simple molecular structures (VPMS) will underachieve significantly on chemistry tests and examinations relative to their spatially able peers.

The populations selected

The 11 experimental samples involved a total of 1600 undergraduate students, of whom 900 were selected for more intensive spatial investigation. Four of the samples were second year medical students, three were second year astronomy students, two were first year chemistry groups (normal and academic support), and two were first year classes of student engineers. The sizes of the samples varied from N=275 in the case of novice engineering students to N=8 in the case of failed anatomy students who returned to repeat a year. The great majority of students were tested between 1980 and 1986, although a few students participated in preliminary interviews prior to 1980.

The nature and characteristics of the nine populations, together with the rationale for their selection, are set out below.

POPULATION I consisted of 38 novice anatomy students who were failed by mid-year (June) in 1980. These were interviewed and tested on a battery of spatial exercises in small groups during August 1980.

POPULATION II consisted of 154 novice students of anatomy who were mass-tested using a battery of geometric spatial exercises in February 1981 - that is, at the commencement of their course. It should be noted that 13 students failed their year of anatomy outright in 1980, and returned to repeat the year in 1981. These were not included in POPULATION II, but were identified separately as POPULATION II(R)

<u>POPULATION III(R)</u> consisted of 8 students who failed their year of anatomy outright in 1982, and returned to repeat their year in 1983. They were tested with two different batteries of geometric spatial tests for the first time in August 1983 - that is after 18 months of lectures, tutorials and practical work in anatomy.

<u>POPULATION IV</u> consisted of 19 novice anatomy students who were failing by mid-year (June) in 1983. They were tested for geometric spatial ability using two different batteries of tests in August 1983.

<u>POPULATION V</u> consisted of 27 science and engineering students attending a popular introductory second year level course in descriptive astronomy. They were interviewed either individually or in pairs during the years 1979 to 1981. A variety of these students' spatial misconceptions in elementary astronomy were probed and recorded for the purpose of developing and refining a diagnostic astronomical spatial test appropriate for university science students.

<u>POPULATION VI</u> consisted of 55 novice students registered for the second year course in descriptive astronomy in 1984. These were mass-tested at the commencement of their year, using both a battery of geometric spatial exercises and a simplified version of the author's newly developed astronomical spatial test called the <u>Novice Astronomical Spatial Test</u>. This was based on the astronomy taught in geography at the ninth grade level in all South African schools.

<u>POPULATION VII</u> consisted of 25 novice students in the 1983 descriptive astronomy course who had intact test and examination results. They were given the author's <u>Full Astronomical Spatial Test</u> in November, at the conclusion of their course, followed by the geometric battery spatial battery which was administered individually.

POPULATION VIII consisted of 275 first year engineering drawing students who were mass-tested using the geometric spatial battery in March 1983, that is, at the commencement of their course.

POPULATION IX consisted of 249 first year engineering drawing students who were mass-tested, using a second, experimental geometric battery and problem solving test, in March 1984, that is, at the commencement of their course.

POPULATION X consisted of 31 remedial freshman first year chemistry students who had been placed in a special Academic Support Programme on their arrival at the University of Cape Town in February 1986. They were mass-tested in March 1986 with the diagnostic VPMS and a standardized one-hour English Language Proficiency Test (ELPT) developed at the University of Cape Town.

POPULATION XI comprised 93 university students enrolled in the normal first year chemistry lecture course, who also wrote the VPMS in 1986.

Procedure

The University of Cape Town's academic year commences in February, and final examinations are written in November. In this study batteries of geometric spatial exercises were designed chiefly by the author, in consultation with two qualified teachers of mechanical drawing, because NFER Spatial Test 3 proved to be too easy for university science students. These were given to different science classes at different times of the year, but no one class attempted a geometric battery more than once during the period 1980-1986. Although the geometric batteries varied slightly from year to year, they had four sub-tests in common. These were designed to measure

1. rotation, visualization and juxtaposition of geometric objects in three dimensions;
2. the identification of diagrams of matching cubes rotated in space;
3. synthesis of sections of common three dimensional geometric objects and
4. diagrammatic sectioning of geometric solids.

A sample item from the geometric spatial battery (GSB) appears in Figure 1.

When the geometric spatial battery was given to novice science classes in February/March, the battery was considered to be chiefly a predictive measure. When the geometric spatial battery was given to science students in August (after the mid-year examinations), the geometric battery was used as both a diagnostic measure in the case of failing students, and as a predictive measure of final examination performance. When the geometric spatial battery was given to classes in November (after the final examination), it was considered chiefly as a diagnostic instrument.

The validity of the geometric spatial battery as a diagnostic measure was also tested on small numbers of repeating students who had failed anatomy during the previous year. One group was tested in February 1981; the other in August 1983. It was suspected that prolonged exposure to a scientific spatially-orientated academic discipline may reduce the effectiveness of a geometric battery for diagnosing spatial weakness.

Different groups of anatomy students attempted the geometric spatial battery at different times during their studies, viz. at 0 months (February), 6 months (August), 12 months (February of their repeated year), and 18 months (August of their repeated year). Different classes of astronomy students attempted the battery at 0 months (February/March) and at 9 months (November). The engineering students attempted the battery at 0 months (March) only.

In addition to the geometric battery, tests of anatomical spatial ability and astronomical spatial ability were also used as predictive and diagnostic measures at several points during various years. The tests of anatomical spatial ability were constructed by lecturing staff in the Department of Anatomy at the University of Cape Town. The tests of astronomical spatial ability were constructed by the author, as was the VPMS for the chemistry students. Sample items appear in Figures 2 - 4.

The design, development, refinement, properties and validation of these various spatial measures are described in detail elsewhere. (Rochford 1984; 1985)

Selection of statistical tests

The significance of the under-achievement of spatially weak students in comparison with spatially able students was determined using t-tests for independent samples.

Regression analyses were employed to establish whether spatial ability, as measured by the various spatial tests used in the investigation, accounts for a significant percentage of the variance in students' academic achievement scores.

Correlational analyses were used to detect significant relationships (which may or may not be causal) between the different variables. Fisher's Z-transformation was employed to examine the significance of differences amongst the individual correlations themselves.

Occasional chi-squared tests and Fisher's exact probability tests were used to test for significant differences between the frequencies of various critical incidents.

Normal probability plots for the computed standardized residuals of the measures used in this investigation showed that the data satisfied the criteria of normality and homoscedasticity. Thus, the statistical tests, which depend on these properties, could be carried out.

The measures

To summarize, the spatial measures employed in this investigation as independent variables were:

(i) a refined geometric spatial battery consisting of four sub-tests, the GSB

(ii) NFER Spatial Test 3 (geometric)

(iii) anatomical spatial MCQ scores

(iv) the VPMS (Visualization of Pictorial Molecular Structures)

(v) the Novice Astronomical Spatial Test (NAST)

(vi) the Full Astronomical Spatial Test (FAST)

The non-spatial measures employed in the investigation as independent variables were:

(i) anatomical non-spatial MCQ scores

(ii) essay examination scores in anatomy

(iii) the Matriculation aggregate symbol

(iv) the English language Proficiency Test

The dependent variables were:

(i) practical examination scores in anatomy

(ii) class test and examination scores in descriptive anatomy

(iii) mid-year and end-of-year examination results in engineering drawing

(iv) class test and examination scores in chemistry.

Refinement of the measures

Error and discrimination analyses were performed on anatomical and astronomical measures of achievement set in MCQ format. Item inversions and ambiguities were detected and eliminated using the procedure recommended by Koeslag, et al. (1979)

Items in the Novice Astronomical Spatial Test and the Full Astronomical Spatial Test were checked for their spatial nature, and for ambiguities, by two lecturers in astronomy who worked independently.

The anatomical MCQs were judgementally classified as either 'spatial MCQs' or as 'non-spatial MCQs' by three different lecturers in anatomy who worked independently. Spatial MCQs required students to visualize in three dimensions; non-spatial MCQs did not. The three lecturers fully agreed on 85% of the 525 MCQs classified, so the remaining 15% of doubtful items were eliminated from the subsequent statistical analysis.

Error, inversion and discrimination analyses were performed on the 40 items in the VPMS after pilot runs during 1985 with 32 senior high school chemistry pupils and 33 young chemistry teachers. The computerised MCQ analysis programme was developed by P. Hurly of the University of Cape Town's Information Technology Services. 36 of the 40 MCQ items in the VPMS proved to be strong discriminators between spatially able and spatially weak chemistry pupils and their teachers. The four remaining faulty MCQ items in the VPMS were subsequently replaced for use in 1986. The final version of the VPMS had the following statistical properties : $r = 0.85$ (KR20). $N = 190$, $\bar{x} = 50\%$, $SD = 24\%$, $SE_m = 9.2\%$

Results

In this investigation a considerable volume of detailed data was produced and analyzed. This may be summarized as follows :

1. Spatially inept students tended to underachieve significantly relative to their spatially competent peers in the following formal academic examinations :
   (a) In practical anatomy and on multiple choice questions which required three-dimensional visualization (POPULATIONS I to IV from 1980 to 1983). See, for example, Tables 2 and 3.
   (b) In descriptive astronomy (POPULATIONS VI and VII in 1983 and 1984). See, for example Table 4.
   (c) In engineering drawing (POPULATION VIII in 1983, and for the subsequent populations of 1984 and 1985). See, for example, Table 5.
   (d) In chemistry (POPULATIONS X and IX in 1986). See, for example, Tables 9 and 10.

2. Spatial ability manifested statistically significant correlations with examination achievement in :
   (a) Practical anatomy, and was always sustained throughout the academic year. See, for example, the BATTERY correlations for POPULATION II (1981) in Table 6 .
   (b) Descriptive astronomy at certain times. See, for example, Table 7 .
   (c) Engineering drawing at all times. Typically $r = 0.65$ ($N = 273$) in 1983; and $r = 0.66$ ($N = 232$) in 1984.
   (d) Most university chemistry tests and examinations (but not with chemistry practical examination scores)..

In addition, regression equations were computed for different subsets of the measures taken with various populations, and the subsets which were most efficiently predicted were established. The analysis with POPULATION II, for example, revealed that the students' spatial battery scores obtained at the commencement of their year of anatomy made a very significant ($p < 0.01$) contribution to the prediction of both their April and June practical examination scores.

Eg. APRIL ANATOMY PRAC. MARK = - 5.527 + 0.403 BATTERY SCORE

 [illegible]278 NOV. ESSAY SCORE + 1.395 FINAL ANATOMY MARK.

3. Subject-based spatial tests were consistently better predictors of academic achievement than both the subject-based non-spatial tests and the geometric spatial battery in :

   (a) Anatomy. See, for example, Table 6. .

   (b) Astronomy. See, for example, Table 7.

   In the case of engineering drawing the geometric battery was far superior to other measures (such as the Matriculation mathematics or science marks) for predicting examination achievement.

4. The predictive validity of all the spatial measures, however, decreased with time in the case of every population investigated in this study, except POPULATION XI (chemistry). E.g. Table 8.

5. The spatial measures in anatomy were found to be most powerful when used as mid-year diagnostic instruments, rather than as early predictors of academic achievement; but, in engineering drawing, they were most effective for identifying students in need of special academic support when administered at the commencement of the course. In descriptive astronomy and chemistry the timing during the year of the diagnostic spatial testing did not appear to be crucial.

6. Thirteen students, who failed their year of anatomy outright in 1980, returned to repeat the year in 1981. Eleven of these thirteen students had failed in 1980 manifesting large, persistant spatial deficits in anatomical spatial MCQ's, as well as failing in practical examinations. They also performed badly on the battery of spatial exercises. These students constituted POPULATION II(R).

   By the end of their second year, however, only six of the eleven spatially inept students were still failing in one or more practical examinations, and only four of these were still recording large spatial deficits in anatomy.

   It appears that the majority of spatially handicapped failed students benefitted spatially from repeating their year, but that several did not, despite two years of intensive teaching and examining.

Implications and recommendations for future research

The findings revealed by the current investigation have several implications for teaching and testing in spatially-orientated subjects at university level:

1. It is recommended that tests of spatial ability alone should never by used to admit or debar any student from commencing a course of study in anatomy, astronomy or engineering drawing.

2. If it is desired to diagnose the existence of spatial weaknesses in students for the purposes of special remedial instruction or prediction, it is recommended that specifically subject-based spatial tests be developed and validated in the particular discipline concerned (such as dentistry, radiology, architecture, crystallography, surveying, and so on); and that purely geometric spatial tests be used as subsidiary, confirmatory, diagnostic instruments only.

3. The optimum time for diagnosing serious spatial ineptitude during a course of study appears to vary from subject to subject. It is recommended that lecturers in different scientific disciplines determine this for themselves by trial and error. In anatomy at the University of Cape Town the optimum time for diagnosis appears to be after six months; in engineering drawing it is at the commencement of the course.

4. If the philosophy of a given university department is to provide special academic support for students with known disabil-

ities, then there appears to be a strong case for extending this support to spatially inept students in anatomy. astronomy, chemistry and engineering as a matter of policy.

5. Finally, an implication of the findings of the present investigation concerns the psychological nature of spatial ability itself. Is it a skill to be developed, or is it an inherited capacity (like handedness or colour-blindness) which can be altered relatively little by experience?

Garry & Kingsley (1970) draw attention to this distinction when they write:

> At any given moment each individual is possessed of certain abilities, that is, available and developed skills for performing acts of varying complexity, and certain capacities or potentials for development of future skills. Abilities are measured by achievement and performance tests; capacities are measured by intelligence and aptitude tests.

The results obtained in the current study appear to indicate that, for most science students, spatial visualization is a skill which can be acquired, though admittedly at widely differing rates. For a small minority of students (perhaps 2%-3%), however, spatial visualization appears to be a capacity for which they have an almost permanently low aptitude.

Many recommendations can be made for future research:

1. Since no previous investigations appear to have been conducted into spatial ineptitude as a significant and likely cause of

under-achievement and failure in both anatomy and descriptive astronomy, there is an open field for research into the development of remedial teaching methods which will prove effective with students who manifest different types of spatial visualization problems.

2. Recent work by Szabo, Dwyer & De Melo (1981) strongly supports the use of properly integrated visualization in the teaching-learning-testing process in human physiology. Whether the format of university theory examination papers in anatomy and descriptive astronomy should be changed to make them diagrammatic, rather than purely verbal, could be investigated.

3. The influence of home language and cultural background on spatial visualization ability in school and university science subjects offers a rich field for research, particularly in South Africa with its diversity of indigenous and immigrant population groups.

4. It is possible that some science students experience not only spatial visualization problems, but other visual difficulties as well, such as figure-ground problems, visual discrimination problems, visual sequencing problems, visual memory problems, visual constancy problems, visual closure problems, and so on. Whilst there appears to be evidence in students' sketches that this may be so, a new and much more rigorous and extensive investigation is required.

5. The current investigation could be repeated in other univer-

sity science subjects such as surveying, physiotherapy, radiography, geology, electron microscopy and architecture, to name just a few.

6. Interactions of spatial ability with other factors such as attitude, home background, hobbies and interests, and so on, could be investigated in different disciplines.

7. The effectiveness of the diagnostic battery of geometric spattial exercises could be explored with different combinations of sub-tests in order to maximize its validity with different types of students.

8. The problem of the early identification of science students who are burdened with a virtually permanent and severe spatial difficulty is, perhaps, the most challenging and urgent area of research awaiting investigations.

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Appendix 1. Examples of spatial and non-spatial MCQ's (November 1980 final examination).

INSTRUCTION: Select the INCORRECT statement from statements 1 to 4 in the following questions, or choose 5 if all four statements are correct :-

54.(SPATIAL) The round ligament of the uterus :

1 lies in the inguinal cancal
2 attaches to the labium majus
3 is situated between the layers of the broad ligament
4 is accompanied by the genital branch of the genito-femoral nerve
5 all 4 statements are correct

70.(NON-SPATIAL)

The following are formed from the mesoderm of the embryo:

1 bone
2 muscle
3 nerve cells
4 blood vessels
5 all 4 statements are correct

72.(SPATIAL)

Answer the following question according to the following key :

1 If A, B, C are correct
2 If A, C are correct
3 If B, D are correct
4 If any other combination (including all four statements), or only one of the statements, is correct
5 If none of the four statements is correct

The posterior triangle of the neck:

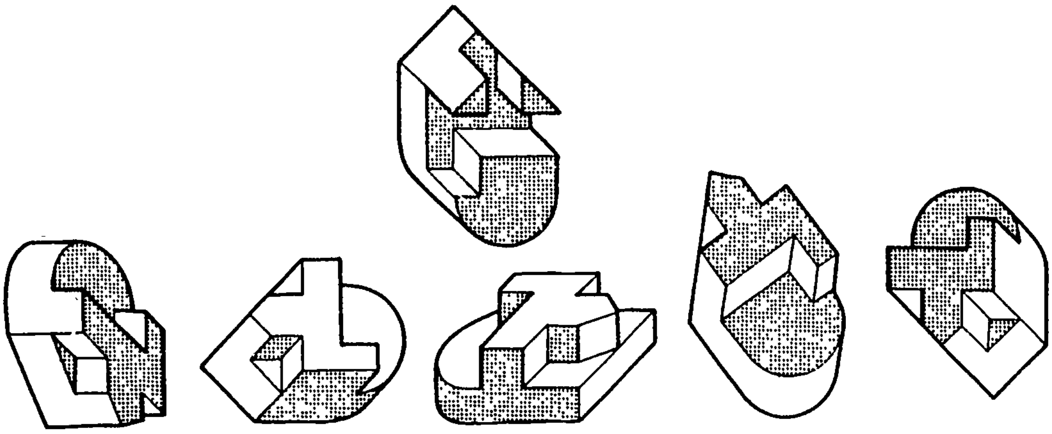
A has the trapezius as its postero-lateral border
B is roofed by the investing layer of the deep cervical fascia
C has the external jugular vein enter it through its roof
D contains the external carotid artery

Figure 1 A sample item from the Geometric Spatial Battery

Rotation and visualization in three dimensions

From the alternative blocks A, B, C, D and E choose the one whose projecting point or points fit exactly into the block with the opening or openings.

There is only one block which fits.

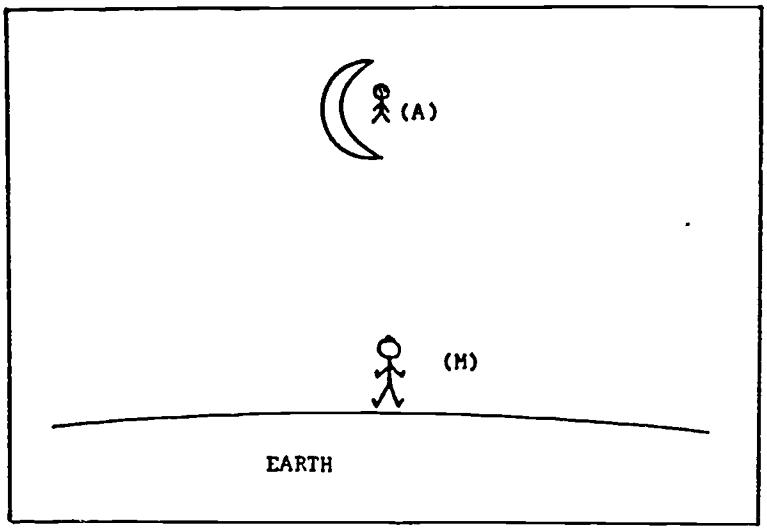


A. B. C. D. E.

Figure 2 Sample item from the Novice Astronomical Spatial Test

(67% of students correct; discrimination index 0.50 - excellent)

(1) The following diagram shows a man (M) standing on the Earth, looking at the crescent Moon. An astronaut (A) is standing on the Moon looking back towards the Earth.



What is the phase of the Earth as seen by the astronaut (A)? Circle the one best answer:-

(1) A crescent Earth

(2) A half Earth

(3) A gibbous Earth

(4) A full Earth

(5) A new Earth

(6) I cannot visualize the answer.

Figure 3 Sample item from the Novice Astronomical Spatial Test (71% of students correct; discrimination index 0.21 - fair)

(6)

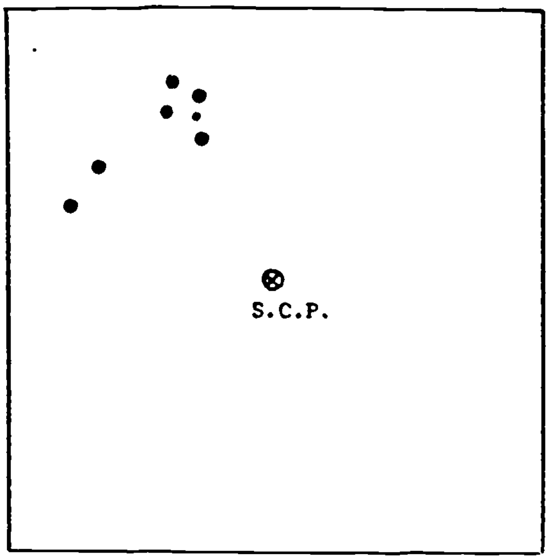


DIAGRAM A

The above DIAGRAM A depicts the position of the Pointers and the Southern Cross relative to the South Celestial Pole at 18h30 on July 30. Twelve hours later, at 06h30 on July 31, the position of the Pointers relative to the South Celestial Pole is depicted in DIAGRAM B. Draw in as accurately as possible on DIAGRAM B below, the new positions of the five main stars of the Southern Cross as they would appear at 06h30 on July 31.

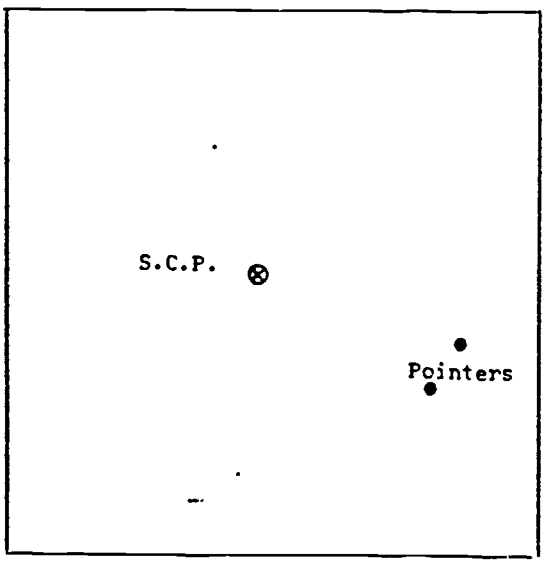
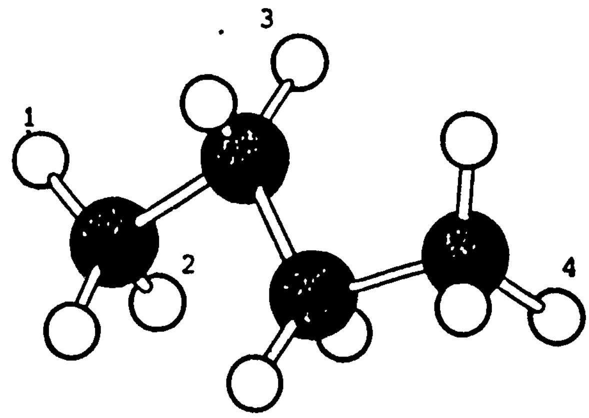


DIAGRAM B

Figure 4 Sample items from the VPMS

Q.3 The diagram on the right is a ball-and-stick representation of a molecule of n-butane C_4H_{10}. The hydrogen atom which is furthest from your eyes, i.e. which is furthest back in the diagram is hydrogen atom number



1

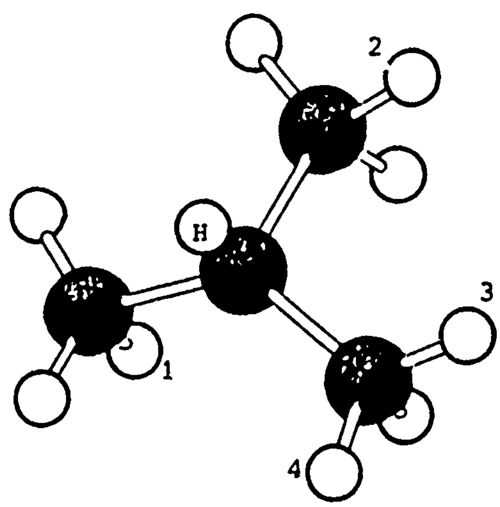
2

3

4

Q.4 The diagram on the right is a ball-and-stick representation of a molecule of isobutane.

The atom which is furthest from the hydrogen atom "H" is atom number



1

2

3

4

Table 1. Typical examples of the performances on spatial and non-spatial examinations in anatomy of students who fail a diagnostic battery of geometric spatial exercises.

STUDENT	SCORE ON DIAGNOSTIC GEOMETRIC SPATIAL BATTERY (%) (PASS MARK 62%)	MCQ EXAMINATION MARKS						PRACTICAL EXAM. MARKS (SPATIAL)			NON-SPATIAL ESSAY MARKS	
		APRIL		JUNE		NOVEMBER						
		SPATIAL %	NON-SPATIAL %	SPATIAL %	NON-SPATIAL %	SPATIAL %	NON-SPATIAL %	APR. %	JUNE. %	NOV. %	JUNE %	NOV %
A	(40)	(36)	63	56	68	(48)	55	(43)	(22)	(39)	52	51
		(-27%)		(-12%)		(- 7%)						
B	(48)	—		(46)	68	(40)	60	(20)	(28)	(38)	50	56
				(-22%)		(-20%)						
C	(23)	(23)	56	(35)	50	(48)	53	(37)	(32)	(43)	62	(48)
		(-33%)		(-15%)		(- 5%)						

FAILING SCORES ARE RINGED.

Table 2 A comparison of the ultimate fates of the geometrically spatially able and the geometrically spatially weak novice anatomy students who were mid-year failures in 1983 (POPULATION IV)

	PASSED THE YEAR AS A WHOLE BY NOVEMBER 1983	FAILED THE YEAR AS A WHOLE: CLASSIFIED AS "FAIL : REPEAT" OR "FAIL : SUPPLEMENTARY"	ABSENT OR WITHDRAWN.
GEOMETRICALLY SPATIALLY ABLE (N = 9)	6	2	1
GEOMETRICALLY SPATIALLY WEAK (N = 10)	2	7	1

Using Fisher's Exact Probability Test, the difference between the ultimate fates of the spatially able mid-year failures and the spatially weak mid-year failures is significant ($p = 0{,}04$).

Table 3 Differences between geometrically spatially able and geometrically spatially weak novice anatomy students who were mid-year failures in 1983 (POPULATION IV) with regard to mean performances on essay, MCQ and practical examinations

	MEAN ESSAY EXAMINATION MARKS (NON-SPATIAL)		MEAN MCQ EXAMINATION MARKS: NON-SPATIAL			MEAN MCQ EXAMINATION MARKS: SPATIAL			MEAN PRACTICAL EXAMINATION MARKS (SPATIAL)			MEAN FINAL YEAR MARK FOR ANATOMY
	APRIL	JUNE	APRIL	JUNE	4 tests combined Apr.-June	APRIL	JUNE	4 tests combined Apr.-June	APRIL	JUNE	NOVEMBER	
GEOMETRICALLY SPATIALLY ABLE STUDENTS (N = 9).	39,8%	21,1%	26,1%	32,2%	39,1%	36,3%	27,7%	39,0%	43,6%	52,7%	54,5%	45,4%
GEOMETRICALLY SPATIALLY WEAK STUDENTS (N=10)	35,6%	17,8%	22,7%	25,3%	32,1%	27,1%	17,4%	25,4%	29,8%	41,0%	43,4%	37,6%
MEAN DROP IN ANATOMY EXAMINATION PERFORMANCE BY SPATIALLY WEAK STUDENTS	-4,2%	-3,3%	-3,4%	-6,9%	-7,0%	* -9,2%	* -10,3%	** -13,6%	* -13,8%	* -11,7%	-11,1%	- 7,8%
	NON-SPATIAL MEASURES					SPATIAL MEASURES						

* Significant drop $p < 0,05$
** Significant drop $p < 0,01$

NOTE: October Practical Marks omitted due to absences by spatially weak students.

Table 4 The effectiveness of a battery of combined astronomical and geometric spatial tests administered in March for predicting performance in November Astronomy examinations.

YEAR	SPATIAL COMPETENCE OF ASTRONOMY STUDENTS IN MARCH.	N	MEAN NOVEMBER ASTRONOMY EXAMINATION SCORE	MEAN DROP
1984	PASS GSB, PASS NAST: "SPATIALLY ABLE"	24	72.0%	- 22.6%**
	FAIL GSB, FAIL NAST : "SPATIALLY WEAK"	10	49.4%	
1985	PASS GSB, PASS NAST : "SPATIALLY ABLE"	37	66.1%	- 7.9%*
	FAIL GSB, FAIL NAST : "SPATIALLY WEAK"	21	58.2%	

** Significant $p < 0.01$

* Significant $p < 0.05$

Table 5 The predictive validity of high and low scores on the March Geometric Spatial Battery with respect to final examination performance in Engineering Drawing in November.

YEAR	FEBRUARY SPATIAL SCORES (%)	N	DISTRIBUTION OF STUDENTS' NOVEMBER EXAMINATION GRADES IN ENGINEERING DRAWING.					
			AV. %	1	2+	2−	3	FAILED/ DROPPED OUT
1983	93 – 100 (Excellent – top sixth of the class)	48	79.6	32	9	6	1	0
	0 – 62 (Fail – bottom sixth of the class)	46	51.4	2	0	7	14	23
1984	93 – 100 (Excellent)	56	74.0	25	14	12	1	4
	0 – 62 (Fail)	32	52.0	1	1	1	12	17

Abbreviations.

AV. = average score

1 = 75% +

2+ = 70% – 74%

2− = 60% – 69%

3 = 50% – 59%

A similar pattern of results occurred in 1985.

Table 6 Corpair Correlation Matrix for the Scores of the 1981 Anatomy Class (N = 154)

	JUNE SPATIAL MCQ	JUNE NON-SPATIAL MCQ	NOVEMBER SPATIAL MCQ	NOVEMBER NON-SPATIAL MCQ	JUNE & NOV. SPATIAL MCQ	JUNE & NOV. NON-SPATIAL MCQ	APRIL PRAC.	JUNE PRAC.	OCTOBER PRAC.	NOVEMBER PRAC.	BATTERY	JUNE ESSAY	NOVEMBER ESSAY	CLASS MARK FIRST SEMESTER	FINAL ANATOMY MARK.
JUNE SPATIAL MCQ	1.00														
JUNE NON-SPATIAL MCQ	0.72	1.00													
NOVEMBER SPATIAL MCQ	0.71	0.65	1.00												
NOVEMBER NON-SPATIAL MCQ	0.67	0.69	0.78	1.00											
JUNE & NOV. SPATIAL MCQ	0.87	0.73	0.96	0.80	1.00										
JUNE & NOV. NON-SPATIAL MCQ	0.75	0.86	0.79	0.96	0.84	1.00									
APRIL PRAC.	0.53	0.49	0.49	0.39	0.53	0.43	1.00								
JUNE PRAC.	0.70	0.56	0.69	0.60	0.74	0.61	0.74	1.00							
OCT. PRAC.	0.58	0.52	0.69	0.65	0.70	0.65	0.50	0.71	1.00						
NOV. PRAC.	0.61	0.52	0.71	0.67	0.72	0.65	0.56	0.79	0.79	1.00					
BATTERY	0.11	0.09	0.06	0.04	0.08	0.02	0.30	0.30	0.14	0.21	1.00				
JUNE ESSAY	0.62	0.55	0.68	0.61	0.70	0.64	0.43	0.68	0.61	0.66	0.09	1.00			
NOV. ESSAY	0.61	0.58	0.70	0.70	0.71	0.71	0.40	0.66	0.65	0.67	0.04	0.76	1.00		
CLASS MARK FIRST SEMESTER	0.80	0.73	0.78	0.70	0.84	0.76	0.75	0.87	0.78	0.80	0.22	0.81	0.76	1.00	
FINAL ANATOMY MARK	0.77	0.71	0.86	0.80	0.89	0.83	0.61	0.82	0.79	0.83	0.15	0.82	0.88	0.94	1.00

Levels of statistical significance

$r > 0.12$	$p < 0.05$
$r > 0.18$	$p < 0.01$

Table 7 Correlations between the scores obtained by POPULATION VII on the tests and examinations in astronomy and the November and December spatial batteries (N = 25)

	Full November Astronomical Spatial Test	Geometric Battery (December)
Test 1 (May)	0.84	0.48
Test 2 (July)	0.83	0.06
Test 3 (Sept.)	0.86	0.18
November Examination Section A	0.87	0.12
November Examination Section B	0.85	0.23
Geometric Battery (December)	0.60	-

SIGNIFICANCE : $r \geqslant 0.22$ $p < 0.05$

$r \geqslant 0.31$ $p < 0.01$

Table 8 Declining predictive correlation coefficients of different spatial tests and examinations in anatomy.

	SPATIAL MCQ		PRACTICAL EXAMINATIONS	
	JUNE	NOVEMBER	JUNE	OCTOBER/ NOVEMBER
APRIL PRAC. (1980, N=43)	0.58**	0.42**	0.79**	0.67**
APRIL PRAC. (1981, N=154)	0.45**	0.44**	0.69**	0.58**
APRIL PRAC. (1981, N=38)	0.52**	0.57**	0.72**	0.65**
AUGUST BATTERY (1980, N=43)	0.32**	0.14	0.53**	0.31*
FEBRUARY BATTERY (1981, N=154)	-	-	0.19**	0.04
JUNE PRAC. (1980, N=43)	0.65**	0.66**	-	(0.67)
JUNE PRAC. (1981, N=154)	0.62**	0.58**	-	(0.69)
JUNE PRAC. (1981, N=38)	0.68**	0.60**	-	(0.70)
(APRIL & JUNE) SPATIAL MCQ (1980, N=43)	-	(0.84)	0.68**	0.67**
JUNE SPATIAL MCQ (1980, N=43)	-	(0.80)	0.65**	0.63**
JUNE SPATIAL MCQ (1981, N=154)	-	(0.61)	0.62**	0.52**
JUNE SPATIAL MCQ (1981, N=38)	-	(0.69)	0.68**	0.59**

N = 43 refers to POPULATION I plus 5 volunteer anatomy students.

N = 154 refers to POPULATION II.

N = 38 refers to the battery failures of POPULATION II.

* Significantly different from zero ($p < 0.05$)

** Significantly different from zero ($p < 0.01$)

TABLE 9 A COMPARISON OF THE ACHIEVEMENT ON CLASS TESTS IN CHEMISTRY OF 31 FIRST YEAR SCIENCE STUDENTS IN AN ACADEMIC SUPPORT PROGRAMME IN 1986, SEPARATED INTO TWO GROUPS OF THE BASIS OF THEIR PERFORMANCE ON AN EARLY DIAGNOSTIC TEST OF THEIR ABILITY TO VISUALIZE ASPECTS OF DIAGRAMS OF SIMPLE MOLECULAR STRUCTURES (THE VPMS)

APRIL VISUALIZATION PROFICIENCY ON VPMS	RANGE OF SCORES ON VPMS (EX 40)	N	MEAN SCORES ON SUBSEQUENT CLASS TESTS AND EXAMINATIONS IN CHEMISTRY			
			JUNE TESTS			NOVEMBER EXAMINATION (%)
			STOICHIOMETRY (EX 50)	ORGANIC (EX 50)	TOTAL (%)	
PASS ($> \frac{20}{40}$)	21 - 37	12	42.1	30.3	72.3	66.1
FAIL ($< \frac{20}{40}$)	10 - 19	19	29.6	28.1	57.7	65.2
		MEAN % DROP	-12.5 = -25% *	-2.1 = -4.2%	-14.6%*	-0.9% N.S.

* SIGNIFICANT DIFFERENCE $p < 0.01$

TABLE 10 A comparison of the achievement on class tests in chemistry of first year science students in 1986, separated into high and low scorers on a diagnostic test of ability to visualize aspects of diagrams of simple molecular structures (the VPMS)

VPMS SCORES	N	APRIL	MAY	AUGUST	SEPTEMBER	PRAC. 1	PRAC. 2
LOW (< 50%)	23	32.1%	48.7%	38.7%	37.7%	32.4%	38.7%
HIGH (> 68%)	29	49.6%	59.3%	50.2%	48.1%	32.7%	42.3%
MEAN % DROP		- 17.5%**	-10.6%*	-11.5%*	- 10.4%*	-0.3%	-3.6%

Significant differences * $p < 0.05$
** $p < 0.01$