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Predicting Academic Success of Engineering Students in Technical Drawing from Working Memory

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Abstract. Tests on spatial aptitude, in particular Visualization, have been shown to be efficient predictors of the academic performance of Technical Drawing students. It has recently been found that Spatial Working Memory (a construct defined as the ability to perform tasks with a figurative content that require simultaneous storage and transformation of information) is strongly associated with Visualization. In the present study we analyze the predictive efficiency of a battery of tests that included tests on Visualization, Spatial Working Memory, Spatial Short-term Memory and Executive Function on a sample of first year engineering students. The results show that Spatial Working Memory (SWM) is the most important predictor of academic success in Technical Drawing. In our view, SWM tests can be useful for detecting as early as possible those students who will require more attention and support in the teaching-learning process.

Key Words: Technical Drawing, Working Memory, Spatial Visualization

MSC 2010: 97G80, 51N05

1. Introduction

Spatial Aptitude is one of the most important abilities needed to work in technical activities related to Engineering and Architecture. All the most important factor studies with spatial tests [2, 8] concluded that Visualization, defined as the ability to manipulate, rotate, twist or invert images of objects, is the most important dimension in Spatial Ability. Moreover, different studies have shown that Visualization is associated with academic performance in Technical Drawing courses [14, 6]. Therefore, several authors have proposed that the teaching-learning process could be more supportive if it were possible to detect early on the students with a low level of Visualization so that a specific didactic treatment could be administered

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[14]. The tasks used in the psychometric tests most employed to measure Visualization are puzzles, paper-folding, cubes, surface development and cross-sections of three-dimensional figures. These are tests that have high *face validity*.

Nonetheless, over the last few decades psychologists have proposed new theoretical models to explain what the basic psychological processes are that underlie individual differences in the performance of visuo-spatial tasks and psychometric tests to measure spatial aptitude. The most important studies have to do with the contribution of *Working Memory* (WM) to complex task performance [4]. WM, a concept proposed by Baddeley from an experimental approach [1], is defined as the cognitive system responsible for the performance of *successive* operations addressed to performance of a complex task: temporary storage and active maintenance of the information in short-term memory, information processing, executive control of the solving process and inhibition of irrelevant information. Baddeley's model includes three components, two of which are specialized for the maintenance of phonological information (*the phonological loop*) and visual and spatial information (*the visuospatial sketchpad*). In addition to these two "slave" systems, the model includes a central control structure called *the central executive*, which is responsible for the control of cognitive processes and for the inhibition of inappropriate responses.

From psychometrics, a perspective other than the experimental one [9, 13], there is a certain consensus as to the definition of the three basic dimensions of WM: *Spatial Working Memory* (SWM), *Verbal Working Memory* (VWM) and *Executive Function* (EF).

- SWM is the ability to perform tasks with a figurative content that require simultaneous storage and transformation of information.
- VWM is the ability to perform tasks that require simultaneous storage and transformation of verbal and numerical information. Simultaneous storage and transformation involve holding mental contents in an accessible state, and performing cognitive operations on the information.
- Executive Function (EF) monitors and controls ongoing mental operations, selectively activating relevant representations and processes and inhibiting irrelevant ones.

Miyake et al. [10] studied the influence of SWM on spatial aptitudes. Using confirmatory factor analysis and structural equations they analyzed a broad battery of spatial tests of Visualization, Spatial Relations and Perceptual Speed, Short-term Memory tests (simple storage of spatial information), SWM tests (storage and processing) and Executive Function classical tasks. They concluded that although SWM and EF contribute to individual differences in three spatial aptitudes, their influence is greatest on the aptitude for Spatial Visualization. These authors speculate that the ability to maintain visuo-spatial representations is important in the three factors, but that performance depends on the complexity of the demands of the tasks. That is, the greater the number and the complexity of the transformations, the greater the involvement of SWM and EF.

Recently several studies have emphasized the influence of Spatial Short-term Memory (SSTM) on WM, arguing that the relations between WM and the general intelligence factor are measured by the extent of short term memory [3, 5]. SSTM requires the maintenance of spatial information, but not any explicit concurrent processing as SWM.

The aim of this study was to analyze the predictive efficiency of tests of Spatial Visualization, Short-term Visual Memory Capacity, Spatial Working Memory and Executive Function on the academic grades earned by engineering students in a Technical Drawing course. The results permit an understanding of the importance of certain relevant cognitive aptitudes when learning technical drawing. In addition, they show the usefulness of aptitude tests in the early detection of students who are likely to encounter difficulties in achieving the objectives of the course.

2. Method

2.1. Participants

In this study 105 first year Engineering students from Paulista State University – Guaratingueta Campus (Brazil) participated. The mean age was 19 and the standard deviation was 3 years. 28.6% of the sample were women.

2.2. Instruments

1. The *Visualization test* (VZt) is based on a Surface Development task. This test was composed of 20 items with 9 options, only one of which was correct. The students had 30 minutes to answer the items. The task consists of a cube that has all faces identified with letters. On the right, the cube is shown unfolded with one of its faces identified with a letter and another face marked with a question mark (?). The student has to identify the letter of the face with the question mark and its relative position (Fig. 1). The score was the number of correct answers. Studies with similar versions of this test show that it is an excellent indicator of the Visualization ability [15, 16, 17].

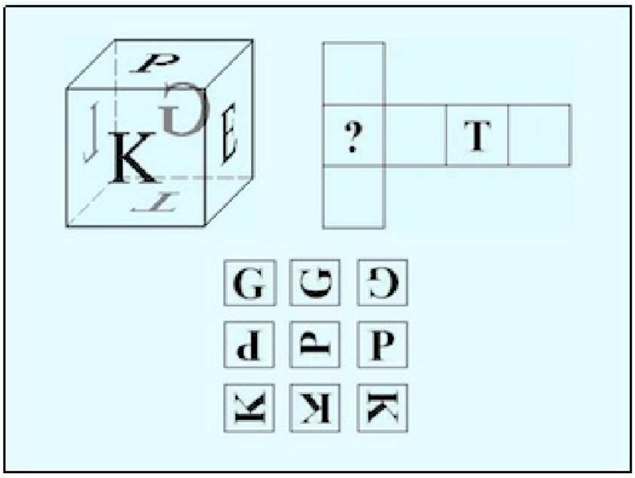

Figure 1: Example from the VZt
The participant has to identify the letter of the face with the question mark and its relative position.

2. The *Spatial Working Memory test* (SWMt) is based on a Letter Rotation dual task [10, 18]. A series of capital letters were presented one at a time for 2 seconds in normal or mirror-imaged position. Each letter was presented in one of seven possible orientations (in 45° increments, excluding the upright orientation). The subject's task is to remember the original orientation of each letter while deciding whether each letter is normal or mirror-imaged. At the end of a trial, the subject reports the initial orientation of each of the letters on a recall

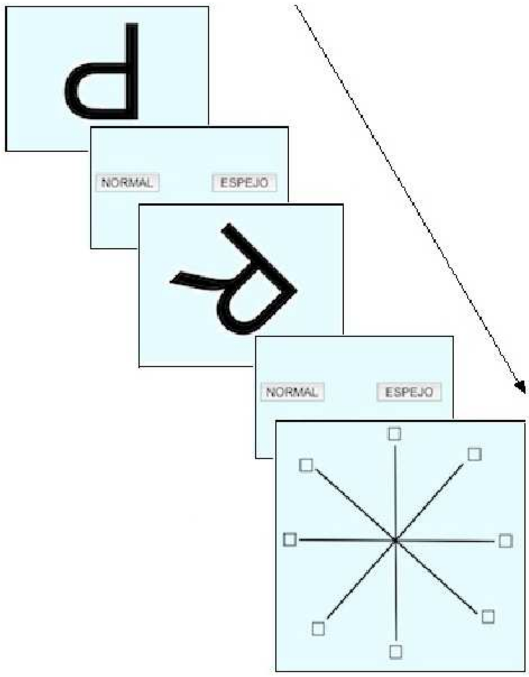

Figure 2: Example from the SWMt
Participants see a series of letters rotated in different orientations and click on the boxes *Normal* or *Mirror* (Espejo in Spanish) imaged. After all the letters, they indicate in an answer grid the location of the top of each letter.

grid in the correct order (Fig. 2). The item score is the maximum number of orientations accurately recalled in the correct serial order. The series (items) increased progressively in size from 3 to 6 letters (16 items total). The test score is the sum of the item scores.

3. The *Spatial Short-term Memory test* (SSTMt) is based on the classical Corsi blocks task [10]. This requires the maintenance of spatial information but does not involve any explicit concurrent processing requirement. Participants are shown a set of 20 items. In each item ten boxes are shown on the computer screen. One box at a time turns blue for 650 ms each. Participants were asked to remember the order in which some of boxes changed color. After a sequence, participants repeat the order by clicking on the boxes with the mouse (Fig. 3). The item score was the number of boxes reproduced correctly. There are three similar but different locations of the boxes to discourage participants from using numerical coding of box locations. Items increased progressively in the number of boxes changing color, from 4 to 8. The test score is the sum of the item scores.

4. The *Executive Function test* (EFt) is an indicator of the supervisory or executive function described by Oberauer et al. [12] as one of the fundamental components of WM, a function that monitors and controls ongoing mental operations and actions, selectively activating relevant representations and processes and inhibiting irrelevant ones. Tasks for assessing EF require participants to activate and keep track of a series of goals and subgoals. More importantly, this goal management must take place in the face of distracting or conflicting information. In each test item the participants are presented with several images in succession. Each image, which appears for 6 seconds, is a square matrix whose cells have arrows that vary

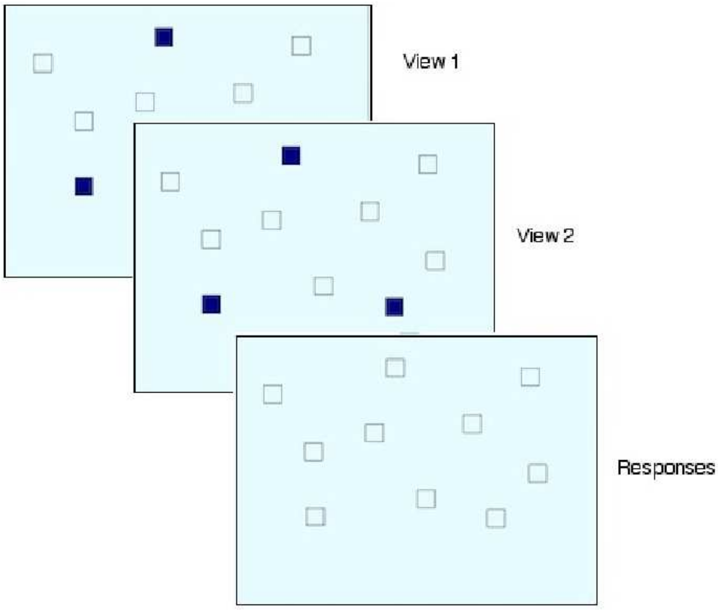

Figure 3: Example from the SSTMt
Participants were asked to remember the order in which some of boxes changed color. After a sequence, participants repeat the order by clicking on the boxes with the mouse.

in the direction they point to (up, down, left or right) and in their color (white, red or blue). To the left of each row a plus or minus sign appears. The participant must count (adding and subtracting) the number of arrows that fulfill a condition in each item (accumulating data from successive screens). The task involves changes in the counting process (additions or subtractions), temporary storage of the result of each screen which the participant must use in successive screens and inhibition of irrelevant instructions, since the cue conditions that have to be counted change between items (Fig. 4). The 20 items increased progressively in number (3 or 4) and size (3×3 or 4×4) of the matrices. The test score is the number of correct answers.

All tests were constructed with the program *LiveCode*, from Runtime Revolution Limited (`http://www.runrev.com/`).

2.3. Procedure

Tests were applied to each participant at the beginning of the Technical Drawing course. The Technical Drawing course in the Engineering Faculty has items characteristic of the graphic area. These include making and interpreting orthographic and pictorial views, imagining sections and details of objects, knowing the norms of technical graphic expression, dimensioning, and being able to efficiently manipulate traditional computerized instruments of drawing.

3. Results

Table 1 shows the descriptive statistics of the variables analyzed: highest and lowest score, mean score, standard deviation and the coefficient for internal consistency (Cronbach's alpha). Cronbach's alpha is a statistic for score reliability that varies between 0 and 1 and indicates the ratio of the variance in the measures to the true variance (without error). As can be observed, the variability in the students' scores is high in the four aptitude tests and the reliability of the scores in most of the tests is acceptable (alpha > 0.70). The EFt shows lower reliability probably because the number of items was not large enough. The variability in the Technical Drawing grades is high and the average performance of the students is moderately high.

Table 1: Descriptive statistics and reliability of variables

Variable	*Min.*	*Max.*	*Mean*	*SD*	*Alpha*
Technical Drawing	2.30	9.80	6.57	1.71	–
VZt	0	20	10.85	4.89	0.85
SWMt	5	69	38.46	17.05	0.92
SSTMt	45	106	80.01	13.72	0.75
EFt	4	19	12.05	3.18	0.60

Min. = lowest score; Max. = highest score; Mean = mean of individuals' scores
SD = Standard deviation; Alpha = Cronbach's alpha

Table 2 shows the Pearson's coefficients of correlation among the variables. As can be seen, there are statistically significant correlations of moderate size between the Technical Drawing grades and the test scores in Visualization (VZt), Spatial Working Memory (SWMt) and Executive Function (EFt). However, the grades do not show a significant association with the Spatial Short-term Memory test (SSTMt). Thus, the first three tests can be used to predict the students' grades in Technical Drawing by means of a multiple linear regression procedure. Yet the high correlation between the Visualization and Spatial Working Memory tests reveals a multicollinearity problem between these two predictors. Multicollinearity occurs when there are high intercorrelations among some set of the predictor variables. In other words, multicollinearity happens when two predictors contain much of the same information.

To clarify the predictive efficiency of VZt, SWMt and EFt on students' performance

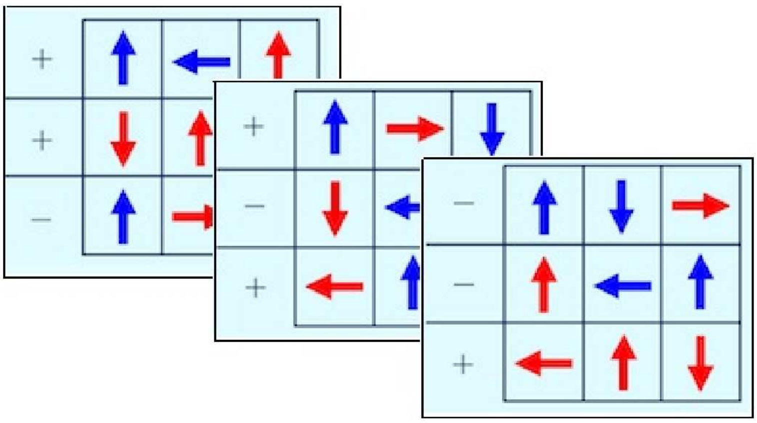

Figure 4: Item from the EFt
Participants must count (adding and subtracting) the number of arrows that fulfill a condition in each item (accumulating data from successive screens).

Table 2: Correlation coefficients for variables

Variable	*VZt*	*SWMt*	*SSTMt*	EFt
Technical Drawing	.27 (**)	.29 (**)	.19	.22 (*)
VZt	–	.57 (**)	.27 (**)	.26 (*)
SWMt		–	.33 (**)	.16
SSTMt			–	.44 (**)

* $p < .05$; ** $p < .01$

in Technical Drawing, we first used a simultaneous method to compute multiple regression: we wanted to see if success in Technical Drawing could be predicted from a combination of other variables, such as Visualization, Spatial Working Memory and Executive Function. The multiple correlation coefficient (R), using all the predictors simultaneously, is 0.36 ($R^2 = 0.13$), meaning that 13% of the variance in Technical Drawing can be predicted from Visualization, Spatial Working Memory and Executive Function. Therefore, although it is statistically significant ($F = 4.20$; $df = 3$; $p = 0.008$), the predictive efficiency is moderate.

Table 3 shows the regression standardized coefficients (Beta) and multicollinearity statistics (Tolerance). The size of the beta coefficients shows the influence of predictors on the dependent variable. The t values measure the significance of the contribution of each variable beyond what is already predicted by other variables. Although the contribution of the linear combination of the three predictors is significant, it can be observed that none of the beta coefficients is statistically significant. It has been pointed out that this paradox may be a problem of multicollinearity [7, 11]. The presence of multicollinearity can cause problems in the interpretation of the regression equation. If there are strong interrelationships among the independent variables, then coefficients estimates cannot be trusted to be meaningful (variables appearing to be insignificant). The tolerance statistic is useful in detecting problems of multicollinearity.

Tolerance is the amount of variance in the individual variable not explained by the other predictor variables. It varies from 0 to 1. A value close to 1 indicates that other predictors do not explain the variance in that variable. A value close to 0 indicates that almost all the variance in the variable is explained by other variables. As a rule of thumb [7], if the Tolerance value is low ($< 1 - R^2$), then there is probably a problem with multicollinearity. As can be seen in Table 3, there is multicollinearity in the variables VZt and SWMt. This strong association replicates the results obtained by Miyake et al. [10], in the sense of the important contribution of Spatial Working Memory to performance in Visualization tasks.

Table 3: Standardized regression coefficients for all predictors

Predictor	*Beta*	*t*	*Sig.*	*Tolerance*
VZt	.13	1.03	.30	.66
SWMt	.20	1.61	.11	.68
EFt	.16	1.57	.12	.95

To overcome the difficulties posed by multicollinearity, combining all the variables showing multicollinearity into a single variable is suggested, as long as this operation is theoretically justified [11]. As we argue in the Discussion section, combining two variables that measure constructs from different psychological trends does not seem advisable from a theoretical perspective. As a result, we chose to estimate a new regression model including only the Spatial Working Memory and Executive Function tests as predictors. In this case, the multiple correlation coefficient (R) is 0.34 ($R^2 = 0.12$), meaning that 12% of the variance in Technical Drawing can be predicted from Spatial Working Memory and Executive Function. This predictive efficiency is slightly lower than (though practically equal to) that obtained with the three predictors (i.e., including Visualization in the equation). As in the previous model, the predictive effectiveness is statistically significant ($F = 5.76$; $df = 2$; $p = 0.004$) and of moderate size.

Table 4 shows the regression standardized coefficients (Beta) and multicollinearity statistics (Tolerance). In this case, it can be observed that the influence of Spatial Working Memory on performance in Technical Drawing is statistically significant and of moderate size (an increase equivalent to a SD in the SWMt implies a change in the Technical Drawing grades equivalent to a third of a SD). In contrast, the influence of the EFt is substantially less and not significant.

Table 4: Standardized regression coefficients for SWMt and EFt as predictors

Variable	*Beta*	*t*	*Sig.*	*Tolerance*
SWMt	.27	2.63	.01	.98
EFt	.18	1.79	.08	.98

4. Discussion and conclusions

In this study we have analyzed in the first place the predictive efficiency of Visualization, Spatial Working Memory and Executive Function tests on the grades students achieved in a Technical Drawing course. The usefulness of this study is both practical and theoretical. From the practical point of view, it helps to identify the psychometric indicators that permit early detection of students with a low level of ability for this kind of activity in a way that allows specific educational treatment to be administered. From the theoretical point of view, an attempt has been made to clarify the predictive efficiency both of tests from the classic psychometric tradition and of those from more recent cognitive approaches.

First of all, we observed that the Spatial Short-term Memory test is not associated with performance in a statistically significant way.

Secondly, we found that the Visualization and Spatial Working Memory tests were highly correlated to each other, and as a result presented problems of multicollinearity.

To surmount the difficulties posed by multicollinearity, it has been suggested that the variables showing it should be combined into a single variable, as long as this can be justified theoretically. In our case, this did not seem to be advisable from a theoretical perspective, as it would involve combining two variables that measure constructs stemming from different psychological tendencies. Visualization is a construct defined within the frame of psychometric theories of intelligence and its measurement is based on performance of tasks with high face validity, given that they are very similar to specific problems that have to be solved in a work or academic environment. That is, the ability to manipulate, rotate, twist or invert images of objects (Visualization) is assessed by the results of performance in complex tasks like *surface development*, *cubes*, *puzzles*, *cutting tridimensional figures*, and *paper unfolding*. In contrast, the Working Memory construct comes from the cognitive and experimental tradition that is more interested in isolating the mental *processes* involved in performance and in individual differences in the implementation of these processes. As a consequence, we decided to use a regression model including only the Spatial Working Memory and Executive Function tests as predictors. The results suggest that the predictive efficiency of the equation that includes Visualization as a predictor is similar to that which included only the tests from the cognitive tradition. What stands out in this case is the influence of Spatial Working Memory, a construct defined as the ability to perform tasks that require simultaneous storage and transformation of figural information. Simultaneous storage and transformation involve holding mental contents in an accessible state, and performing cognitive operations on the information. As was to be expected, the influence of this construct on academic performance in Technical Drawing is modest. A complex variable such as academic performance is usually related to a variety of other factors (motivation, self-esteem, academic background, effort, and many other variables).

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