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Spatial Skills in Education: A National Study

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SPATIAL SKILLS IN EDUCATION: A NATIONAL STUDY

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ABSTRACT

It is widely accepted that spatial skills play an inherent role in educational success, especially in STEM disciplines such as Engineering, Mathematics and Graphics. This paper presents an initial investigation into spatial skills in post-primary education where the aim is to generate a national spatial profile to assist in developing meaningful educational interventions. Psychometric tests of spatial ability were administered to a cohort of 1st year pupils (n = 451) in a variety of educational contexts. Findings suggest that this early stage in post-primary education may be an auspicious time to integrate spatial skill development into formal education and that the relationship between subject choice and impact with spatial skills merits further investigation.

KEYWORDS: Spatial skills, STEM, Post-primary education

1. INTRODUCTION

In a recent report, the National Science Board [1] identified that STEM talent has always been associated with a high proficiency in literacy and numeracy, but that this needs to be expanded to include high levels of spatial ability. Despite substantial evidence associating high levels of spatial ability with success in STEM education [2, 3, 4], the development of spatial skills is typically not part of formal education systems. However, there has been a recent paradigm shift towards initiating interventions targeting cognitive developments of this nature.

Over the last two decades, an intervention has been designed to specifically target spatial skill development [5]. This intervention has been administered in multiple universities across the U.S. and results consistently illustrate statistically significant increases in students' levels of spatial ability. Subsequently, students who engaged in this intervention also demonstrated increased performance across a number of STEM disciplines including Engineering, Calculus, Chemistry, Physics and Computer Science.

The magnitude of these results has led to the formation of the National Spatial Skills Research Network (NSSRN) in Ireland. The network consists of researchers across three universities; University of Limerick, Dublin Institute of Technology, and Dublin City University, who aim to investigate spatial ability from a pedagogical and cognitive perspective.

The scope and intent of the network is to examine the position that spatial cognition has within the Irish formal education system in the view towards developing and implementing authentic and meaningful interventions which will ultimately lead to increased educational success for pupils and students. With initial work focussed at post-primary level, specifically in STEM disciplines, the current agenda is to establish a national *spatial profile* which will aid in achieving this aim. This paper report on initial results obtained through the generation of this profile for pupils in their 1st year of post-primary education.

2. METHOD

2.1. Approach and Participants

The particular focus of the current study is to examine pupils’ spatial profiles in their 1st year of post-primary education. The full study will include a cohort of approximately 2500 pupils across 28 post-primary schools. Three psychometric tests of spatial ability which are described below will be administered to each participant in a paper and pencil format to establish a national profile. This will be explored in conjunction with additional variables including subject choice, subject impact on spatial skills, and gender differences.

Specifically, this paper reports on a preliminary data sample (n=451) which was gathered across four unique educational contexts. Demographic information for each of the schools involved at this stage is presented in Table 1.

Table 1. Demographic information of participating schools and associated gender distributions of participants from the current study

| School | Location | Gender | Fee-Paying | Ethos/Religion | Pupils | Participant Gender | | | n |
|--------|----------|--------|------------|----------------------|--------|--------------------|--------|---------|-----|
| | | | | | | Male | Female | Unknown | |
| SCH1 | Urban | Mixed | No | Inter Denominational | ≈1100 | 97 | 76 | 4 | 177 |
| SCH2 | Urban | Mixed | Yes | Church of Ireland | ≈300 | 20 | 16 | | 36 |
| SCH3 | Rural | Mixed | No | Inter Denominational | ≈500 | 43 | 49 | | 92 |
| SCH4 | Urban | Mixed | No | Inter Denominational | ≈900 | 77 | 69 | | 146 |

2.2. Design and Implementation

As previously discussed, expedited versions of three psychometric tests of spatial skills which are well established within the pertinent literature are the primary methodological tools involved in this study. They include the Purdue Spatial Visualisation Test: Visualisation of Rotations (PSVT:R) [6] which examines the capacity to mentally rotate complex three dimensional objects, the Mental Cutting Test (MCT) [7] which elicits capabilities pertinent to mentally cutting 3-dimensional objects and the Space Relations subtest of the Differential Aptitude Test (DAT:SR) [8] which assesses the cognitive ability of developing surfaces of 3-dimensional objects. These tests were selected as they span multiple spatial factors specifically attributed to spatial skills including spatial relations (PSVT:R) and visualisation (MCT and DAT:SR) [9, 10]. All tests were administered in a

paper and pencil format in the participants' schools either by a member of the research team or by a school teacher trained in administering the tests by the research team. Demographic information was also gathered as well as information pertinent to subject uptake, specifically for Technical Graphics (TG) and Art. The results were subsequently digitised to facilitate in data analysis.

3. FINDINGS

Prior to conducting any statistical analysis to gain insight into the nature of spatial skills in the cohort, the sample was investigated to identify if it was normally distributed and plausibly representative of the envisioned full study cohort. The results of this analysis are presented in Table 2. The skewness and kurtosis values illustrate that the sample achieved near normal distributions across each of the psychometric tests and for the accumulated total results.

Table 2. Descriptive statistics of participant results

| Measure | N | Min | Max | Mean | Std. Deviation | Skewness | | Kurtosis | |
|---------|-----|------|--------|-------|----------------|-----------|------------|-----------|------------|
| | | | | | | Statistic | Std. Error | Statistic | Std. Error |
| DAT:SR | 451 | 0.00 | 100.00 | 34.66 | 22.23 | .662 | .115 | -.283 | .229 |
| PSVT:R | 451 | 0.00 | 100.00 | 35.50 | 22.26 | .554 | .115 | -.137 | .229 |
| MCT | 451 | 0.00 | 80.00 | 26.34 | 16.03 | .477 | .115 | -.002 | .229 |
| Total | 451 | 3.33 | 86.67 | 32.17 | 14.83 | .658 | .115 | .417 | .229 |

Subsequent to analysing the data for normality, the participants were divided into quartiles based on the accumulation of their results across each of the three tests. The values for each quartile were; Q1 = 23.33%, Q2 = 30%, Q3 = 43.33%, Q4 = 86.67%. Boxplots illustrating these quartiles and statistical outliers as well as a cumulative frequency curve which illustrates the quartile values are presented in Figure 1 below.

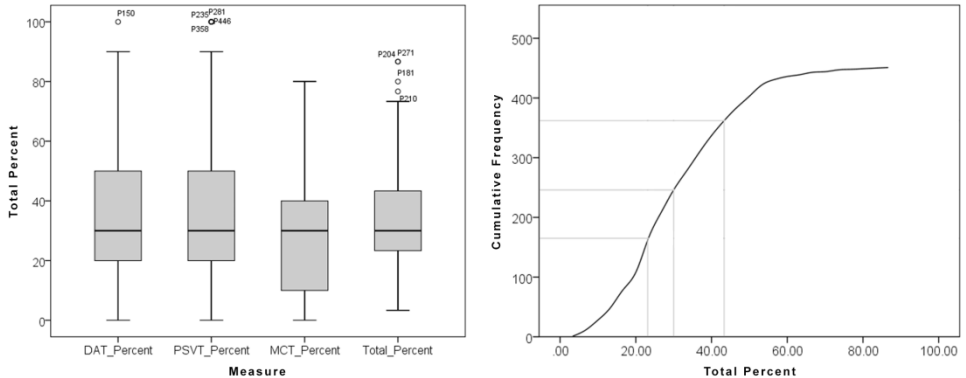


Figure 1. Boxplots illustrating the results of each psychometric test and total scores (left) and a cumulative frequency distribution curve illustrating cumulative frequencies of participants in each quartile (right)

As expedited versions of each of the three tests were utilised in this study, ascertaining the reliability of these versions is paramount in supporting their continued use and further investigation in this study. The expedited DAT test

achieved a Cronbach’s Alpha value of .629, the expedited PSVT:R achieved a value of .613, and the expedited MCT achieved a value of .350. All of these values are considerably lower than Alpha values recorded in studies utilising the full versions of the tests. D’Oliveira [11] recorded an Alpha value of .95 for the full DAT:SR test, Maeda and Yoon [12] report Alpha values for the full PSVT:R from a variety of studies ranging from .81 to .86, and Kelly Jr et al [13] reported a KR20 value of .815 for the full MCT. The low internal consistency between the items in each test suggests a review of the items which should be extracted from the full versions. However, considering these results in conjunction with the relatively low performance across each test may suggest that this cognitive faculty is not entirely developed at this age. This postulated malleability may imply early post-primary education is an opportune time to introduce spatial skill development into the formal education system.

As previously presented, this study is concerned with investigations pertinent to relationships between subject choice and engagement with spatial skill development as well as gender differences in spatial skills. To identify any potential relationships between subject areas and spatial skills two chi-square tests of independence were performed between the variables of studying both TG and Art, and being in a specific quartile. The relationship between quartiles and studying TG was significant, $\chi^2 (3, n = 451) = 33.001, p = .000$ with a small effect size ($\phi = .271$). The relationship between quartiles and studying Art was also significant, $\chi^2 (3, n = 451) = 13.591, p = .004$, again presenting a small effect size ($\phi = .174$). A more detailed account of this relationship is presented in Figure 2.

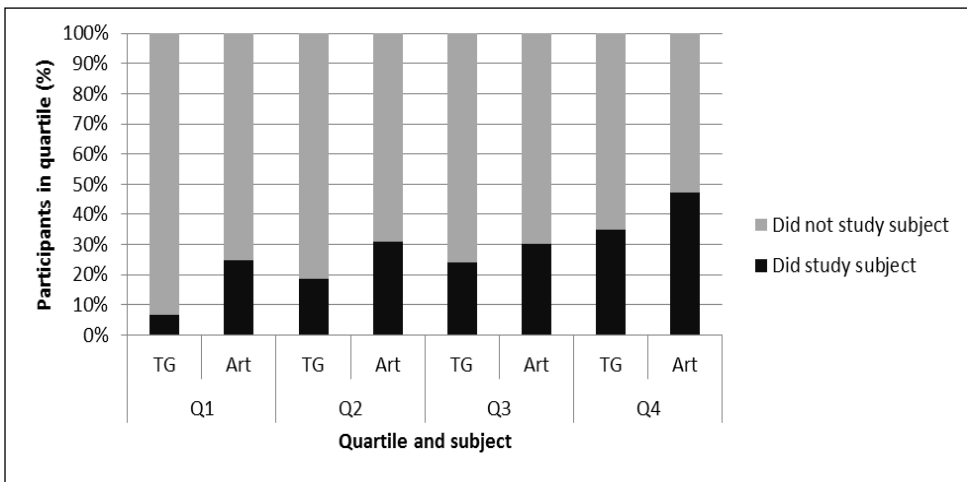


Figure 2. Percentages of participants in each quartile studying TG and Art

Finally, a series of independent samples t-tests were conducted to identify any statistically significant gender differences across each of the three tests and for the accumulated scores. The results of these tests are presented in Table 3 and indicate no statistically significant differences pertinent to gender.

Table 3. T-test results examining gender differences across each psychometric test and for total scores

| Measure | Male | | Female | | <i>t</i> | <i>df</i> | <i>p</i> |
|---------|--------|----------------|--------|----------------|----------|-----------|----------|
| | Mean | Std. Deviation | Mean | Std. Deviation | | | |
| DAT:SR | 33.671 | 21.323 | 35.714 | 23.349 | -0.962 | 426.007 | 0.337 |
| PSVT:R | 36.625 | 24.486 | 34.191 | 19.603 | 1.166 | 440.588 | 0.244 |
| MCT | 26.034 | 17.008 | 26.476 | 14.770 | -0.294 | 444.825 | 0.769 |
| Total | 32.109 | 15.750 | 32.127 | 13.858 | -0.012 | 445 | 0.99 |

4. DISCUSSION

This study has presented a number of interesting results from a pedagogical perspective. As evidenced by the low mean scores for each of the psychometric measures (see Table 2), the participants in this study appear to have underdeveloped spatial skills compared to the level they are typically reported at in higher education. For example, to pass the PSVT:R, 1st year higher education students need to achieve a grade of 60% [5]. This is posited as the rationale for the low reliability scores for each of the tests utilised in this study. If the inherent difficulty level in the task was too high for the pupils, there is high potential for inconsistencies in their negotiations of the tasks. This hypothesis is supported by mean results in each test attained by both genders. One of the most consistent findings in spatial ability research is a statistically significant gender difference favouring males [5, 14]. However, studies of this nature typically involve a cohort of an older demographic. Not seeing such a difference further supports the idea that at this age spatial skills are malleable, presenting an opportune time for the integration of developmental interventions.

Examining participants' uptake of TG and Art yields further interesting results. While the effect sizes were low, a trend can be noticed which identifies engagement in these subject as being associated with higher spatial skills. This trend is stronger for TG and generates the questions; 'are students acutely metacognitively aware of their cognitive capacities and selecting subjects accordingly?' and 'does engagement with these subjects support the development of spatial skills?' It is not currently possible to conclusively answer these questions, however the relationship between spatial skills and subject uptake and impact is an interesting research direction within education.

5. CONCLUSION

This early work presents two critical findings for spatial skills research in education. Primarily, it appears that in 1st year of post-primary education, pupils have an underdeveloped cognitive faculty of spatial ability. Due to the cognitive malleability apparent at this age, this suggests a potentially auspicious opportunity to implement interventions which may significantly support pupils throughout their entire education. In addition to this, the relationship that levels of spatial ability have with subject choice, as well as the impact that subjects can have on the development of spatial skills merit further consideration.

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