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National Spatial Skills Project - Preliminary Findings of Phase One

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SPACE

Spatial Ability in Education

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List of Secondary Schools where testing was undertaken

Ardscoil Phadraig, Granard, Co. Longford

Borris Vocational School, Borris, Co. Carlow

Cabra Community College, Cabra, Dublin 7

Colaiste Bride, Clondalkin, Dublin 22

Colaiste Choilm, Tullamore, Co. Offaly

Colaiste Pobail Setanta, Clonee, Co. Dublin

Dominican College, Griffith Avenue, Dublin 9

Killina Secondary School, Killina, Co. Offaly

Mercy Secondary School, Inchicore, Dublin 8

O'Carolan College, Nobber, Co. Meath

Pobailscoil Neasáin, Moyclare Rd, Dublin 13

Portlaoise College, Portlaoise, Co. Laois

Portmarnock Community School, Portmarnock, Co. Dublin

Sacred Heart Secondary School, Tullamore, Co. Offaly

Scoil Mhuire, Trim, Co Meath

ScoilMhuire Community School, Clane, Co. Kildare

St. Aidan's Comprehensive School, Cootehill, Co. Cavan

St. Colmcille's Community School, Knocklyon, Dublin 16

St. Dominic's Secondary School, Ballyfermot, Dublin 10

St Fergal's College, Rathdowney, Co. Laois

St. Mary's C.B.S., Portlaoise, Co. Laois

St. Mark's Community School, Tallaght, Dublin 24

St. Patrick's Classical School, Navan, Co. Meath

St. Joseph's Secondary School, Stanhope St., Dublin 7

Stratford College, Rathgar, Dublin 6

Sutton Park School, Sutton, Dublin 13

Templeogue College, Templeogue, Dublin 6W

Trinity Comprehensive, Ballymun Rd, Dublin 9

Summary

The overall aim of this project is to determine the role that spatial ability plays in academic success in STEM disciplines across all level of the Irish education system. Research studies carried out across many countries, including Ireland, have shown that spatial skills and reasoning play a central role in determining a student's perceptions of STEM subjects and disciplines, and significantly impacts on their ability to succeed in these areas. This research is being carried out to establish the levels of spatial ability across all levels of education in Ireland and to introduce education interventions and learning activities to increase students' spatial skills. It is also being carried out to establish if there is a difference in scores between male and female students and to determine the relationship between subject selection and spatial skills.

Spatial ability has long been considered a key indicator of intellectual ability as evidenced by the inclusion of spatial tasks in many intelligence tests. Spatial ability was described by Thurstone (1938) as being a critical component of intellectual ability. Thurstone (1950) cites seven factors related to human intelligence, three of which referred to visual orientation in space:

- The ability to recognise the identity of an object when it is seen from different angles;
- The ability to imagine the movement or internal displacement among parts of a configuration;
- The ability to think about those spatial relations in which the body orientation of the observer is an essential part of the problem.

Understanding students' spatial ability and where necessary improving students' spatial skills is widely considered to be a key factor for preparing students' for careers in STEM (science, technology, engineering and maths) related disciplines.

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1 Introduction

1.1 Project Overview

The preliminary findings presented in this report are taken from a collaborative research project being undertaken in Ireland, the United States of America and Australia. This document reports only on the data collected in Ireland where the project is being undertaken by researchers from Dublin Institute of Technology (DIT), University of Limerick (UL) and Dublin City University (DCU). The primary aim of the project is to gather empirical data from second level students in order to establish a baseline value for spatial ability. The initial phase of testing targeted first year students and was administered between the months of February and May, 2016.The test used was comprised of 10 questions each from the Differential Aptitude Test: Space Relations (DAT:SR), the Purdue Spatial Visualisation Test: Visualisation of Rotations (PSVT:R) and the Mental Cutting Test (MCT). Each of the tests used measures a distinct area of spatial visualisation ability and are highly regarded in research communities. Overall, approximately 2500 first year students from 28 schools were tested. This research was carried out following full ethics approval from the Dublin Institute of Technology Research Ethics Committee (Ethical Clearance Ref 15-42).

1.2 Research Network

In Ireland, the project is being undertaken by researchers drawn primarily from two research groups; CREATE (Contributions to Research in Engineering and Applied Technology Education) which is based in DIT and TERG (Technology Education Research Group) which is based in UL. While both groups exist separately, members have come together to form a wider network of educational researchers known as NSSRN (National Spatial Skills Research Network), which has a particular focus on spatial visualisation ability.

1.2.1 CREATE (Contributions to Research in Engineering and Applied Technology Education)

In 2001, the Physics Education Research Group (PERG) was established in DIT and over the next 12 years evolved to include education research in a wide range of disciplines. To reflect this growth and diversity CREATE was established in September 2013. CREATE is an interdisciplinary research group within DIT which includes education researchers from a wide range of disciplines including Physics, Mathematics, Engineering, Computer Science, Sociology and Education. CREATE supports and fosters education research and strives for excellence in STEM education research. Regardless of context or objective, all CREATE research studies are situated in an epistemological position, underpinned by education theory and involve a rigorous methodological approach and meticulous data analysis whether it is qualitative or quantitative.

1.2.2 TERG (Technology Education Research Group)

TERG was established in the Department of Design and Manufacturing Technology at the University of Limerick in 2010. Its main emphasis is to promote research and scholarly studies into teaching and learning within the suite of technology subjects at second level. TERG supports a thriving research community with a particular focus on research into teaching, learning and assessment in the area of Technology Education. The University of Limerick is the leading provider of initial technology teacher education programmes in Ireland and TERG continually strives to lead pedagogical innovation in this area through pioneering research and evidence based teaching. The current research activities and projects undertaken by members of TERG explore the traditions and practices of teaching and learning in technology education, particularly in the areas of epistemology of technology education, technology pedagogy, technological capability and literacy as well as spatial cognition.

1.2.3 NSSRN (National Spatial Skills Research Network)

The National Spatial Skills Research Network (NSSRN) was established in 2015 with the support of funding from the Irish Research Council (IRC) under the 'New Foundations' scheme and operates under the mission statement of 'Enhancing STEM Education'. The network comprises of researchers from the University of Limerick, Dublin Institute of Technology and Dublin City University - and is joined by various international researchers in its aim of exploring spatial ability. The general aim of the group is to lead investigations into spatial ability with particular focus in the educational, psychometric and cognitive domains. Current research activities by group members correlation studies of spatial skills, in particular the spatial relations or complex mental rotations factor, and academic performance in STEM disciplines as well the development of a cognitive map of the domain of spatial ability to facilitate the progression of further spatial ability research.

1.3 Objectives of the Project

1.3.1 Phase One - Obtain Baseline Data

The initial objective of the project was to gain an insight into the spatial abilities of secondary school students by gathering baseline data from first year students in each of the participating schools. This will now contribute to the construction of a national profile of spatial ability. From the sample it is possible to establish the spatial ability of first year students before they progress through second level education. This report marks the end of this phase with the initial results disseminated to the participating schools and other stakeholders. In addition a spatial skills training intervention will be provided in the transition year programme to improve students' spatial ability in preparation for the senior cycle.

1.3.2 Phase Two- Extend Data Collection and Commence Spatial Skills Training Intervention

As the first phase of testing is complete and a baseline of the level of spatial ability in first year has been obtained, phase two of testing will commence in September 2016.This will involve testing students from first to sixth year in the second level education system to gain insight into how students' spatial ability develops as they progress from years one through six.

1.3.3 Long Term Objectives

The long term objective of the project is to understand the role that spatial ability plays in academic success in STEM disciplines across all level of the Irish Education system. This knowledge will be used to develop training programmes and/or modify curricula to improve academic achievement and progression in STEM disciplines.

2 Background to Study

2.1 Spatial Ability

Spatial ability is commonly defined as the ability to manipulate 2 and 3-dimensional shapes in one's mind. It is commonplace in the field of educational research to draw distinction between 'spatial ability' and 'spatial skills' and many misconceptions have arisen in the area of classification of spatial factors. Three major factors used to test the spatial ability of an individual were identified by Lohman and Kyllonen (1983): spatial relations, spatial orientation and spatial visualisation.

- Spatial Relations: "The ability to imagine rotations of 2-dimensional and 3-dimensional objects as a whole body" (Martin-Dorta, Asorin and Contero, 2008).
- Spatial Orientation: "The ability to orient oneself physically or mentally in space" (Maier, 1998)
- Spatial Visualisation: The "ability to mentally manipulate, rotate, twist and pictorially invert presented visual stimuli" (Gorska and Sorby, 2008)

The following sections explain the difference between 'spatial ability' and 'spatial skills'.

2.1.1 Spatial Ability

Numerous definitions exist for the term 'spatial ability'. One definition refers to it as having "the ability to generate, retain, retrieve, and transform well-structured visual images" (Lowman, 1993). Spatial ability is the ability to visualise an image or object and is a facility an individual possesses before any formal training has taken place. Spatial ability can be further explicated as a cluster of abilities distinct from verbal and mathematical reasoning (Jones et al, 2008) and can be viewed as a cognitive characteristic of intelligence that provides a measure of one's ability to conceptualise the spatial relations between objects.

2.1.2 Spatial Skills

Spatial skills are a set of skills acquired through formal training (Sorby, 1999) and represent one's prowess in appropriately utilising spatial abilities to perform a task. In the case of students in second level education, it is almost impossible to distinguish between spatial abilities and spatial skills because it is almost impossible to ascertain what prior knowledge or training a student has received before beginning their post primary education. For this reason, the terms "spatial ability" and "spatial skills" are used interchangeably in this context.

2.2 Rationale for Testing

Research studies carried out across many countries, including Ireland, have shown that spatial skills and reasoning play a central role in determining a student's perceptions of STEM subjects and disciplines and significantly impacts on their ability to succeed in these areas. Through STEM education research and development, carried out predominantly in the United States of America, education interventions have been developed to improve students' spatial skills. These interventions, or short courses, have been tested, amended and retested over many years at both second level and higher education in the United States of America. They have been introduced as compulsory courses in higher education in many Universities in the United States of America (Sorby, 2014) with the aim of attracting students to STEM education, increasing student retention, improving students' abilities in STEM subjects and preparing more students in STEM disciplines.

As this project evolves, students will have the opportunity to undertake a spatial skills training intervention to further develop their spatial skills.

2.2.1 Success in STEM Education

There is overwhelming evidence linking spatial skills to success in STEM (Shea et al, 2001; Smith, 1964; Wai et al, 2010; Delahunty et al, 2015). Recent articles link spatial skills to creativity and technical innovation (Kell et al, 2013) and to success in computer programming (Jones et al, 2008). A longitudinal study following 400,000 highs school students 11 or more years later, investigated both their choice of college major and career. It found that adolescent spatial reasoning skills were predictive of choice of STEM majors and careers, above and beyond the effects of verbal and mathematical abilities (Wai et al, 2009).

Spatial ability has emerged as a consistent and statistically independent predictor of selecting STEM related courses, graduate study, and other measures of STEM attainment. Thus, it is now clear that spatial ability plays a critical role in developing expertise in STEM (Wai et al, 2009). There is evidence that spatial ability predicts course selection and success in physics (Talley, 1973; Kozhevnikov et al, 2007; Mac Raighne et al, 2015). Furthermore, spatial visualisation skills have been correlated with achievement in chemistry (Talley, 1973; Wu and Shah, 2004); engineering (Duesburyand O'Neil, 1996; Gerson et al, 2001) and geology (Kali and Orion, 1996; Orion et al, 1997).

2.2.2 Gender Differences

It is well documented that the 3-Dimensional spatial visualisation skills of women lag behind those of their male counterparts, especially for 3-Dimensional rotations (Tartre, 1990; Linn and Petersen, 1985; Voyer et al, 1995). Many theories have been put forward to try and explain these differences including the assertion that spatial ability is related to a male sex hormone (Hier and Crowley, 1982) or reflects males evolutionary focus on hunting (Silverman et al, 2000). Other theorists suggest that environmental factors are the primary reasons for male female differences in spatial skill levels (Fennema and Sherman, 1977).

In prior research (Sorby and Baartmans, 1996; Leopold et al, 1996; Medina et al, 1998) it was found that although men and women both have statistically significant gain scores through participation in engineering graphics courses, the average post-test scores for women are still lower than the average pre-test scores for men (Hand, Uttal et al, 2008). A meta-analysis of gender differences in spatial ability identified significant differences in mental rotation tasks (Voyer et al,1995), in favour of male participants.

In a study carried out by Lippa et al (2009) the performance of more than 90,000 women and 111,000 men from 53 countries who took a mental rotations test was investigated. It found a gender difference in favour of males which is clearly evident from Figure 1.

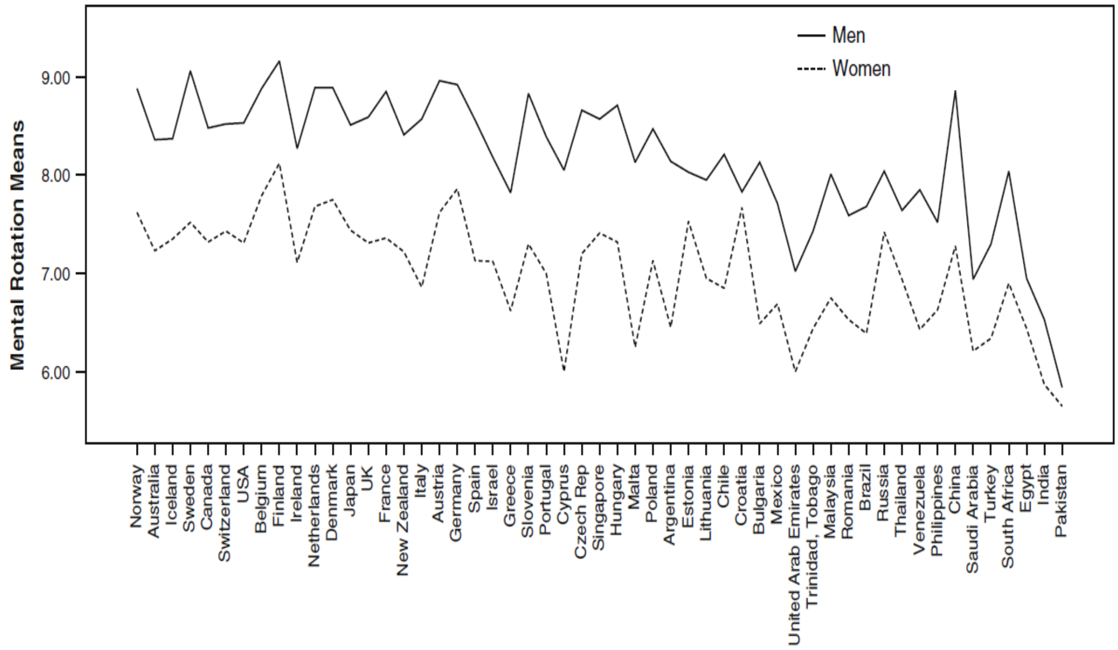

Figure 1: Comparison of results of a Mental Rotation test across 53 countries.

(From Lippa et al, 2009)

2.3 Test Instrument

The items used in the study presented in this report were taken from the Differential Aptitude Test: Space Relations (DAT:SR), Purdue Spatial Visualisation Test: Visualisation of Rotations (PSVT:R) and the Mental Cutting Test (MCT). Each test measures a different aspect of spatial ability and are combined here help to provide a profile of the spatial abilities of secondary school students at all levels. These tests are well established in the measurement of spatial ability and are used internationally.

2.3.1 Differential Aptitude Test: Space Relations

The Differential Aptitude Test (DAT) is a collection of tests designed to measure students' verbal and numerical reasoning, mechanical reasoning, perceptual ability, spatial relations, abstract reasoning, spelling and language use. It tests a students' ability to recognise and transform patterns. For this study a subset of the Differential Aptitude Test: Space Relations (DAT:SR) was used to measure students' ability to move from a 2-dimensional to a 3-dimensional environment.

The DAT:SR is commonly used to measure a students' ability to visualise a 3-dimensional object which has been created from a 2-dimensional pattern. It requires the student to mentally fold a 2-dimensional pattern and choose the correct 3-dimentional object which would result from the original 2-Dimensional pattern from a set of four alternatives. The test consists of 10 questions, a sample of the type of question found on the DAT:SR is provided in Figure 7 in Appendix A.

2.3.2 Purdue Spatial Visualisation Test: Visualisation of Rotations

The Purdue Spatial Visualisation Test: Visualisation of Rotations (PSVT:R) is an instrument utilised in educational research to measure a students' rotational spatial ability. Developed by Roland Guay in 1976 at Purdue University, it represents one of the three sections (Developments, Rotations, and Views) comprising the Purdue Spatial Visualisation Test.

Each question on the test begins with an example, showing an object in its initial and rotated positions, followed by another object, along with its five different rotated positions. The student must then choose one rotated position that has resulted from the same rotation as the given example (Yoon, 2011). The test consists of 30 questions, a sample question from the PSVT:R is provided in Figure 8 in Appendix A.

2.3.3 Mental Cutting Test

The Mental Cutting Test (MCT) is an instrument used to measure a students' ability to cut a 3-dimensional object with a given cutting plane. It was developed as part of the Special Test in Spatial Relations (College Entrance Examination Board [CEEB], 1939) and was once used as a university entrance exam in the United States of America. Students have to mentally cut a three-dimensional object using a given cutting plane. Once cut, the students must identify the correct surface which results from the cutting process. The MCT measures both spatial visualisation and spatial relations. The test consists of 25 questions, a sample question from the MCT is provided in Figure 9 in Appendix A.

2.3.4 Test Administration

The test consisted of 30 questions in total comprising of 10 questions from each of the tests described above. The test was administered in 3 distinct sections and was completed in pen and paper format. Students were permitted 21 minutes to complete the test with 7 minutes per section. All tests were supervised by a member of the research team and at least one teacher or a teacher alone.

3 National Results

3.1 Summary of Testing to Date

Between February and May 2016 the spatial ability of nearly 2500 first year second level students in Ireland were tested. Tests were administered in 28 schools in order to get a snapshot of the level of spatial ability of first year students' in the Irish second level education system. A breakdown of participating secondary schools base on gender and type is given below:

- School Denomination
  - Male - 5 Schools
  - Female - 6 Schools
  - Mixed - 17 Schools
- School Type
  - Voluntary Secondary School - 21 Schools
  - Educational Training Board (ETB) School - 7 Schools

Table 1 provides a summary of the data obtained. For comparison purposes the results have been presented as percentages.

	Count	DAT:SR	PSVT:R	MCT	Total
Total	2464	39%	35%	26%	34%
Male	1215	41%	38%	26%	35%
12yo	193	39%	35%	25%	33%
13yo	927	40%	38%	26%	35%
14yo	95	44%	39%	27%	37%
Female	1182	38%	33%	26%	32%
12yo	236	38%	30%	26%	31%
13yo	896	40%	34%	27%	33%
14yo	50	36%	34%	27%	32%

Table 1: Summary data by gender and age.

Table 1 shows the average scores for the three different tests and the full test (combining the 3 different tests). While testing was anonymous, students were asked to provide some supplementary information for analysis. The additional information gathered were personal characteristics such as gender, age and subjects taken. Sections 3.2 to 3.5 provide a summary of the data obtained during phase one of the study.

3.2 Score by Gender

Analysis of the total scores by gender (see Figure 3) indicates a slight difference in favour of male students. This is consistent with international research. The data labels on top of each bar indicate the number of students in each denomination.

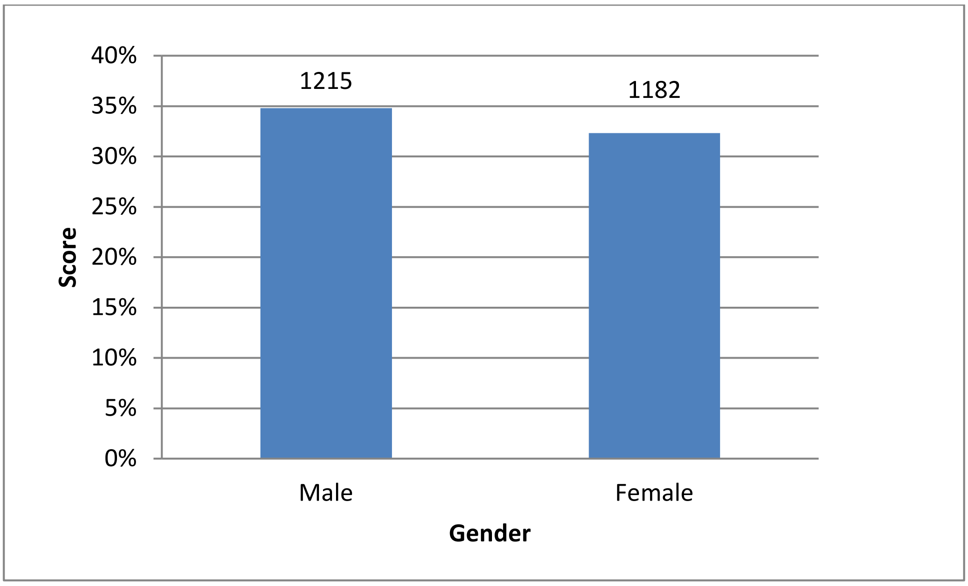

Figure 2: Students' score by gender.

3.3 Score by Age

In this study student ages ranged from 12-14 years of age. Figure 3 provides a comparison of the normalised total scores for all students aged 12 to 14. In all age categories it is clearly evident that male students outperform their female counterparts. The normalised total score for male students also increases with age. Despite an increase for female students from 12-13 years of age there is a decrease from 13-14 years of age. It should be noted that the sample size of 14 year old females was small relative to the size of the overall sample and thus this aspect will be investigated in phase 2.

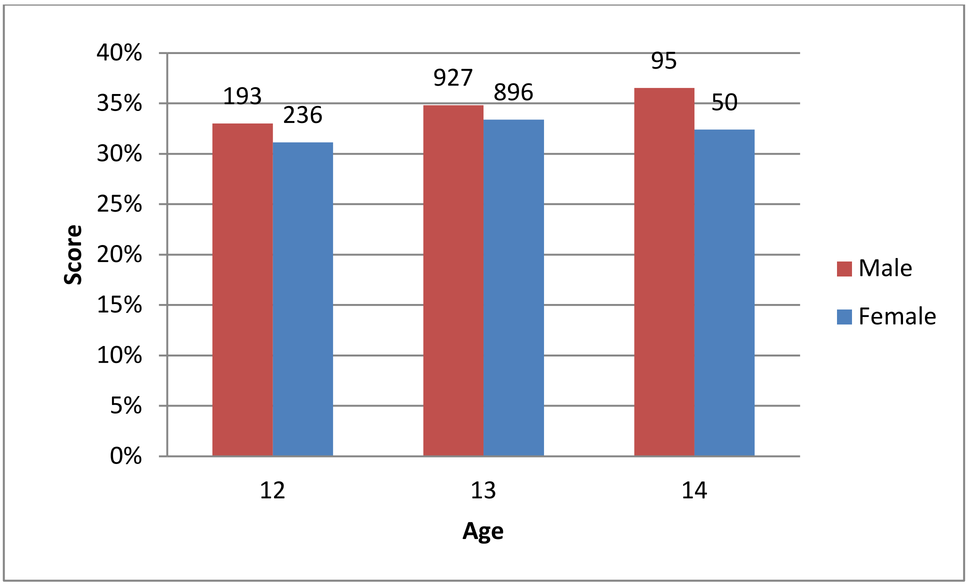

Figure 3: Students' score by age and gender.

As part of separate studies, the spatial ability of first year higher education engineering students was examined. In total 65 students from two level 7 engineering programmes offered by Dublin Institute of Technology (DT004 - B. Eng. Tech. Civil Engineering; DT097 - first year common engineering)were tested using the same instrument and under the same conditions. When compared with second level students, the gap in total score (see Figure 4) is almost double. This may indicate that students with high spatial ability are more likely to choose STEM programmes in higher education and it also suggests that spatial ability can be improved with formal training (Nevin et al, 2015; Farrell et al, 2015).

It should be noted that the third level students are a self-selecting group in so far as they have chosen to study a STEM discipline. At second level the majority of students may not form an opinion on what career they would like to pursue until they reach senior cycle.

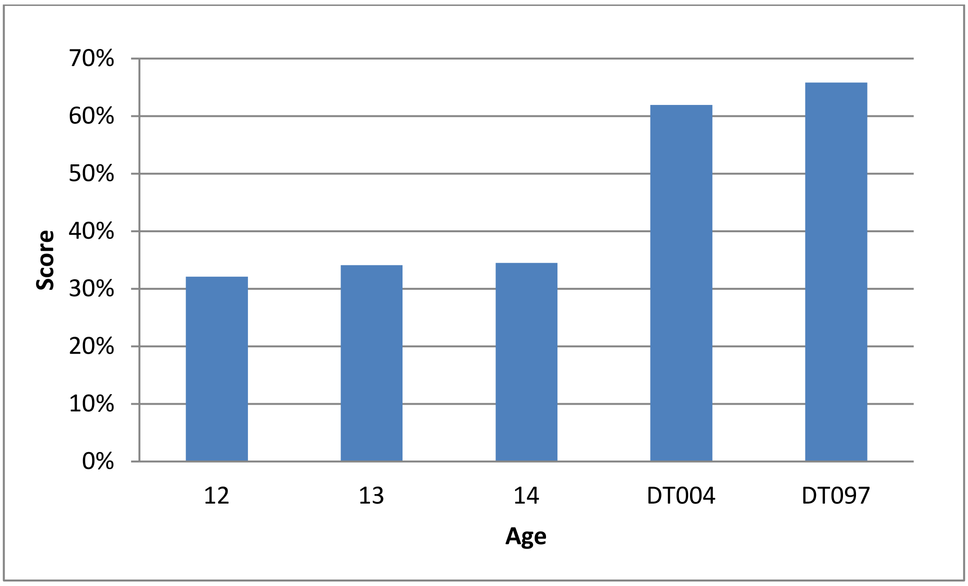

Figure 4: Comparison of normalised total scores for first year students in second and third level

3.4 Score by Subject

Students were asked to indicate whether they were studying Art or Technical Graphics and in schools where taster courses were offered students were asked to indicate whether they had an interest in studying Technical Graphics or Art. It is clear that a larger proportion of male students study or show an interest in Technical Graphics when compared to their female counterparts.

Gender	Subject(s)	Number of Students
Male	Unspecified	402
	Art	460
	Technical Graphics	577
	Both	210
Female	Unspecified	526
	Art	627
	Technical Graphics	106
	Both	56

Table 2: Summary of subject choice as indicated by participants.

While it is too early to say it is possible that subject choice may be a contributor to the development of spatial skills. Figure 5 shows a breakdown of scores by subject and it would appear to indicate that there is very little gender difference between subject choices. It does appear that students taking subjects which nurture hand-to-eye ability score better than those who do not. However, what is not clear at this stage is whether these subjects are developing spatial skills or if students with higher spatial skills are more likely to choose these subjects, or if it is a combination of both.

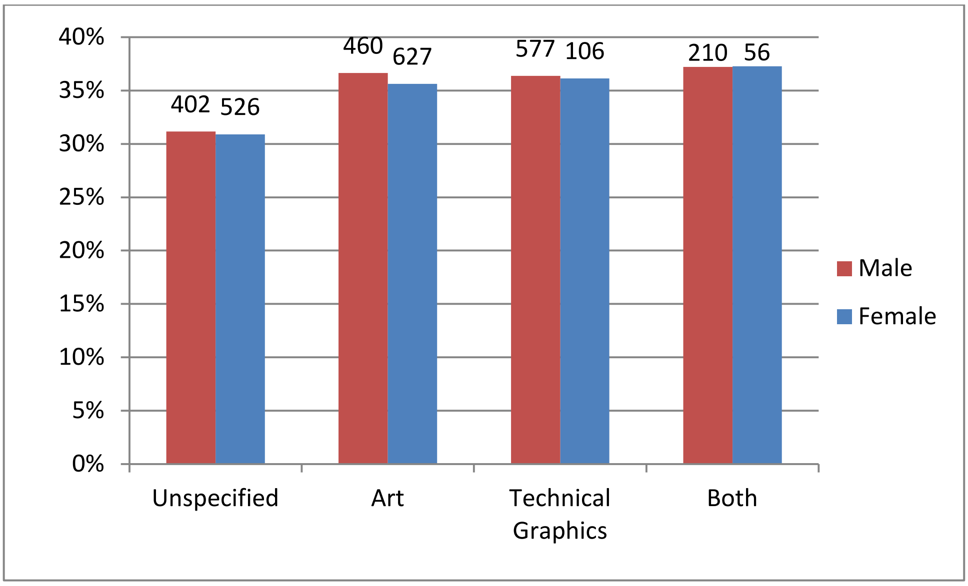

Figure 5: Student score by subject choice and gender.

3.5 Range of Scores

The range of scores separated by gender is provided in Figure 6. While the majority of both male and female students lie in the lower range of scores (0-15), the data presented shows that a larger proportion of males than females lie in the higher range of scores (16-30).

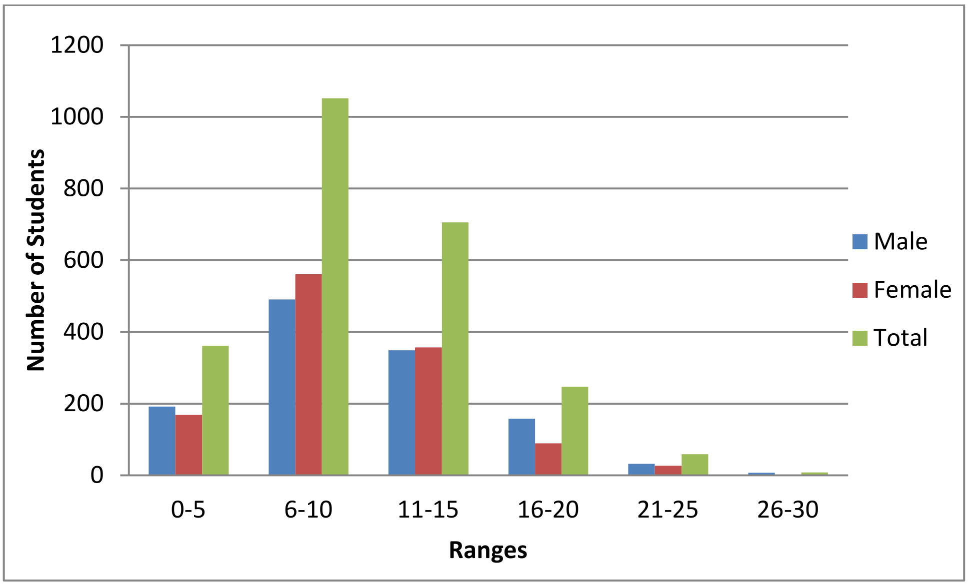

Figure 6: Range of scores achieved by gender.

4 Conclusions

4.1 Preliminary Observations from Phase One

From the data presented in section 3a number of provisional observations may be made:

- Figure 2 suggests that there is a gender difference favouring male students. A number of theories have been put forward to try to explain the existence of this difference. While none of them are universally accepted the gender difference here certainly warrants further research.
- From Figure 3 it appears that spatial ability improves with age. However, male students see larger gains year-on-year than their female counterparts. The extent of this gain will be examined as subsequent years are tested.
- Figure 5 indicates that students who take subjects which encourage hand-to-eye coordination score better on average that those who do not.
- Table 2 shows the number of students who indicated they take Art, Technical Graphics or both. Only 106 female students indicated that they take Technical Graphics compared with 577 males. Interestingly, students who study both subjects show no significant gender difference.
- A larger proportion of male than female students lie in the higher range of scores (see Figure 6), from 16-30.

4.2 Future Research

- As this study evolves it is envisaged that spatial ability tests will be administered to all years, from first to sixth, within participating schools. This will help to gain a better understanding of the level of spatial ability at second level and to gauge student preparation for STEM disciplines.
- The introduction of a spatial skills course in the transition year programme will be used to help improve students' spatial skills in preparation for their senior cycle and Leaving Certificate examinations. Pre and post testing will be carried out to determine if the intervention has a positive influence on test scores. This research will form the basis of a detailed report on the long term efficacy of these interventions.

4.3 Spatial Skill Intervention Programme

Constraints on resources mean that the long term viability of this project lies in training second level teachers to administer the spatial ability test and to deliver the spatial skills intervention programme as part of the Transition Year programme.

To facilitate this, a series of two two-day training courses are scheduled run in September 2016. These training courses will insure that teachers in participating secondary schools are equipped with the necessary knowledge and skills to administer the test and deliver the course themselves. Throughout the training course support will be provided from researchers actively involved in the project. The training will form part of a validated CPD course (5 ECTS at Level 8). For more information about the training courses, please feel free to contact us.

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Appendix A: Sample Questions

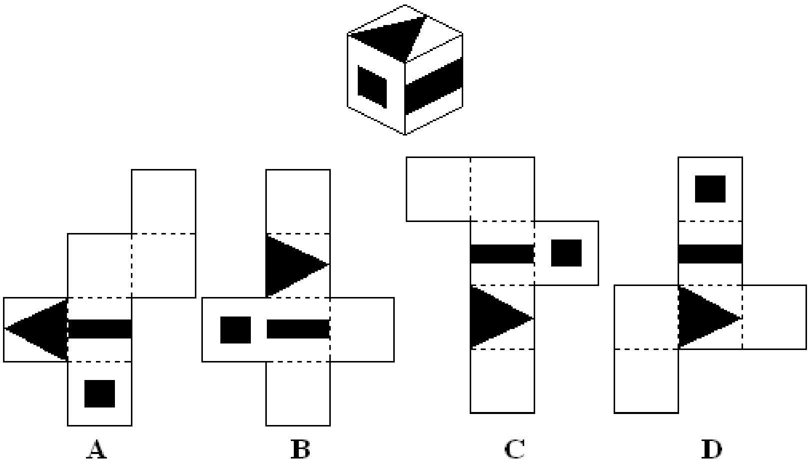

Figure 7: An example problem from the DAT:SR.
(correct answer is B)

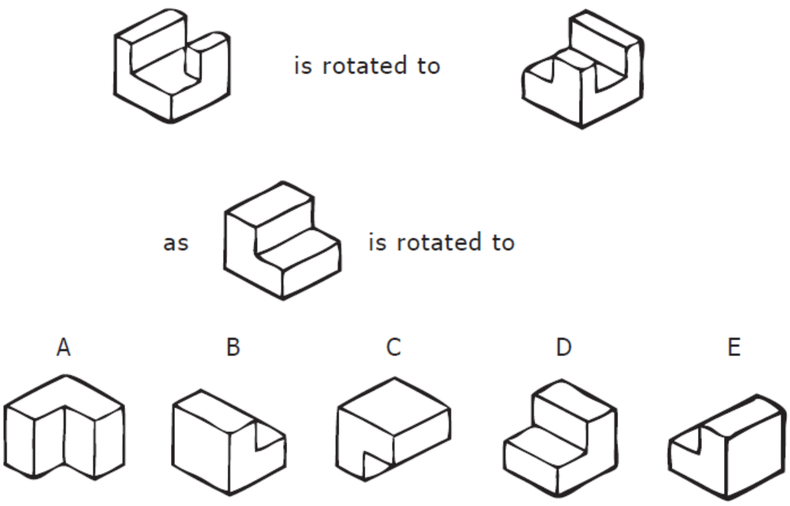

Figure 8: An example problem form the PSVT:R.
(correct answer is D)

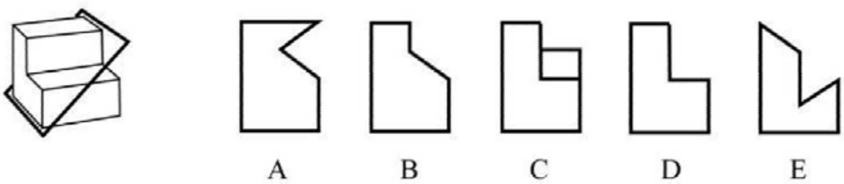

Figure 9: An example problem from the MCT.
(correct answer is D)

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