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Blending a Spatial Skills Intervention into a Mainstream Technology Teacher Education Degree Program

Dr. Diarmaid Lane, University of Limerick

Dr. Lane is a Lecturer in Technology Teacher Education at the University of Limerick. His research interests are in the areas of freehand sketching, cognition and spatial visualization. He is currently Director of Membership of the Engineering Design Graphics Division (EDGD).

Dr. Sheryl A. Sorby, Ohio State University

Dr. Sheryl Sorby is currently a Professor of STEM Education at The Ohio State University and was recently a Fulbright Scholar at the Dublin Institute of Technology in Dublin, Ireland. She is a professor emerita of Mechanical Engineering-Engineering Mechanics at Michigan Technological University and the PI or coPI on more than $9M in grant funding, most for educational projects. She is the former Associate Dean for Academic Programs in the College of Engineering at Michigan Tech and she served at the National Science Foundataion as a Program Director in the Division of Undrgraduate Education from January 2007 through August 2009. Prior to her appointment as Associate Dean, Dr. Sorby served as chair of the Engineering Fundamentals Department at Michigan Tech. In this capacity, she was responsible for the development and delivery of the newly adopted First Year Engineering Program at Michigan Tech. She received a BS in Civil Engineering, an MS in Engineering Mechanics, and a PhD in Mechanical Engineering-Engineering Mechanics, all from Michigan Tech. Dr. Sorby has a well-established research program in spatial visualization and is actively involved in the development of various educational programs.

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Introduction

Flexibility in mentally manipulating geometry (spatial ability) is a fundamental skill that deserves careful attention when designing courses of study in engineering and technology education. Numerous research studies have correlated high performance in spatial skills tests with high grades in STEM (science, technology, engineering and mathematics) disciplines at university level. In a longitudinal study conducted by Wai et al. [1] it was found that the likelihood of earning an advanced degree in STEM is directly related to spatial ability[1].

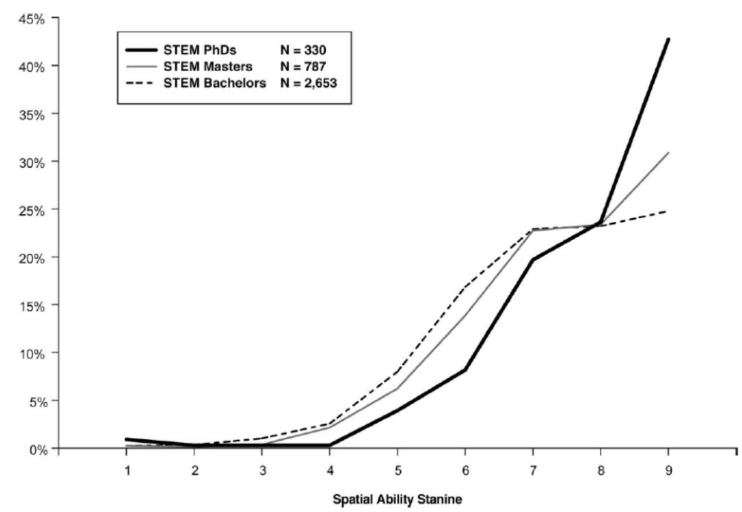

Figure 1 - Participants drawn from a randomised sample of U.S. high schools (Grades 9-12, N=400,000)[Wai et al.[1]]

As part of a 2005 British Broadcasting Corporation (BBC) documentary, *Secrets of the Sexes*, a total of 255,114 people took an internet survey on human sex differences [2]. The survey included a six-item mental rotation test and a 20 item line angle adjustment test. The data for the mental rotation element is shown in Figure 2.

[1] Figure 1 illustrates an 11-year study where a randomized sample of 400,000 high school students (Grades 9-12) were tracked to the end of their third level studies. Spatial ability is broken into nine categories (or stanines) where '9' is the highest level of attainment in spatial tests taken at high school and '1' being the lowest level of attainment.

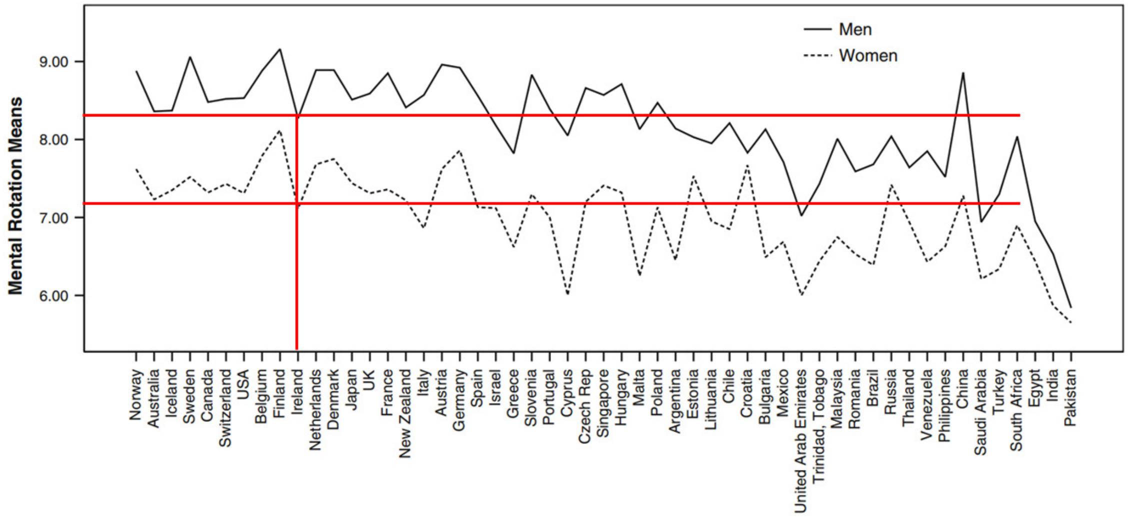

Figure 2 – Men's and women's mental rotation means across 53 nations (with the most gender egalitarian nations at the left and least egalitarian at the right) [2]

This paper is primarily concerned with the performance of Irish males and females and it is notable that the performance of both males and females is lower than most gender egalitarian nations. Interestingly, as part of a study on spatial skill metrics, Ernst et al. [3] reported that a group of semester 2 freshmen (n=52) on an initial technology teacher education program at the University of Limerick (Ireland) scored 77.4%. When compared to Michigan Technological University (MTU), an average PSVT:R score of 83.3% for 237 engineering major students during orientation was reported by Veurink & Sorby [4]. It should be noted that the students on the program at the University of Limerick had completed a graphics course in the previous semester, while the students at MTU were tested at orientation, prior to enrollment in any courses at the university. Further evidence of the assertion that Irish students fall behind in terms of spatial skills is found in Sorby et al. [5]. In this study, spatial skills of first-year engineering students at Dublin Institute of Technology (DIT) were significantly behind those of their Michigan Tech counterparts. DIT students were also behind similar students at Cracow University of Technology (Poland) and at Kaiserslautern University (Germany). These findings correlate with the data presented in Figure 2 where research participants in the USA outperformed Irish counterparts and raise the question; *are Irish high schools facilitating the development of visual communication and spatial skills, and to what degree?*

Irish Second Level (High School)

The Irish high school system is divided into two parts, Junior Cycle (typically 12-15 year olds) and Senior Cycle (typically 15-18 year olds). The key skills for both the Junior Cycle [6] and Senior Cycle [7] are shown in Table 1.

Table 1 – Key skills for Junior and Senior Cycle

Junior Cycle Key Skills	Senior Cycle Key Skills
1. Managing myself	1. Information processing
2. Staying well	2. Critical and creative thinking
3. Communicating	3. Communicating
4. Being creative	4. Working with others
5. Working with others	5. Being personally effective
6. Managing information and thinking	

Skills such as visual communication, craft skills, problem solving and creative thinking all form part of the key learning outcomes for shop based subjects such as woodwork, metalwork and technology, in addition to dedicated graphics subjects at both levels. This raises the question – *Why are Irish males and females underperforming in spatial skills assessments if the education system is promoting a broad development of all aspects of the individual?* This question is further explored in the next section in the context of a semester 1 freshman graphics course on an initial technology teacher education program.

An insight into Design and Communication Graphics 1

Design and Communication Graphics 1 (PN4011) is a first semester course offered to students on a four year Initial Technology Teacher Education (ITTE) program at the University of Limerick. The course is the first in a series of six courses solely dedicated to graphics that the students study over the four years. The purpose of PN4011 is to facilitate the development of students understanding and knowledge of fundamental graphical concepts and principles while facilitating the exploration of these using different communication strategies such as freehand sketching and CAD. A key element of the course is the development of students' spatial visualization skills. The spatial visualization intervention developed by Sorby [8] was used for this purpose.

Lane et al. [9] previously described the philosophy and structure of a new ITTE program at the University of Limerick. PN4011 was first rolled out in the autumn semester 2014 replacing PN4001 (Technical Graphics 1). 122 students (116 male and 6 female) enrolled in the new course. Table 2 gives a breakdown of the course contact hours each week with a brief description of the purpose of each element.

Table 2 – Weekly contact time for PN4011

Element	Duration	Purpose
Lecture	2 hours per week over 12 weeks	• Develop students' knowledge of the underpinning literature associated with graphical education. • Scaffold students understanding of key concepts and principles
Lab	4 hours per week over 10 weeks	• 2 hours of time dedicated each week to the development of spatial skills • 2 hours of lab time to facilitate students in applying knowledge of concepts and principles by completing various graphical tasks through the medium of freehand sketching and CAD
Tutorial	1 hour per week over 10 weeks	• Facilitate students ability to externalize perceived visual information through the medium of freehand drawing
Private Study	3 hours per week over 12 weeks	• During this time, students are encouraged to revise course material, revise lab work based on formative feedback refine freehand drawing skills and critically reflect on their own learning experiences

The next section of the paper describes the implementation of the spatial visualization skills intervention during the course labs along with pre and post-test data.

Spatial Visualization Skills Intervention

In order to obtain a measure of spatial ability, the Purdue Spatial Visualization Test of Rotations (PSVT:R) was administered to all students who were in attendance during the first lecture of the semester. One hundred and twenty (120) students completed the pre-test. The results for this are detailed in Table 4. As this test was administered during the first week of semester 1, it is valid to compare with the scores reported by Veurink & Sorby [4] where the average PSVT:R test score of engineering major students at orientation was 83.3%. Further, for the Michigan Tech sample ~ 18% of the students were female, compared to less than 5% of the UL sample. Since significant gender differences exist, favoring males, this would mean that the UL students are actually even further behind the Michigan Tech students in terms of spatial skill levels, if data were to be disaggregated by gender. This again correlates with the data presented in Figure 2 and raises further questions about the level of spatial skills of Irish second level students.

Table 3 – Pre and post-test results for PN4011

N	120
Minimum (%)	33.3
Maximum (%)	100.0
Mean (%)	69.19
Std. Deviation	16.03

The spatial visualization skills intervention was integrated into the two of the four lab hours every week over a ten week period. The workbook and accompanying software by Sorby [8] were the primary source of reference of these labs. We found that two hours dedicated to each of the ten chapters in the intervention were sufficient to facilitate a steady progression for all students. All students were provided with 15 snap-cubes which they brought with them into each 2 hour lab (Figure 3). The labs were facilitated by a graduate teacher of engineering graphics.

Figure 3 – Classroom environment for the spatial skills intervention

Rather than solely completing the workbook using the special software, other activities and resources were also integrated into these two hour labs. Although many of the objects illustrated in the workbook can be constructed using snap-cubes, we observed that some students struggled when they couldn't build the configuration. In order to scaffold these students, we encouraged them to create a 3D file of the object they were having difficulty with using SolidWorks and subsequently build a physical model of the object using a rapid prototype machine. The primary purpose of this element of the intervention was to facilitate students in physically holding and manipulating the geometry in order to help them construct and mentally rotate the visual mental image associated with the problem at hand. It is important to note that this scaffold was treated as a last resort and that most students were able to independently create and manipulate the mental image without the reference to the object created using the rapid prototype machine.

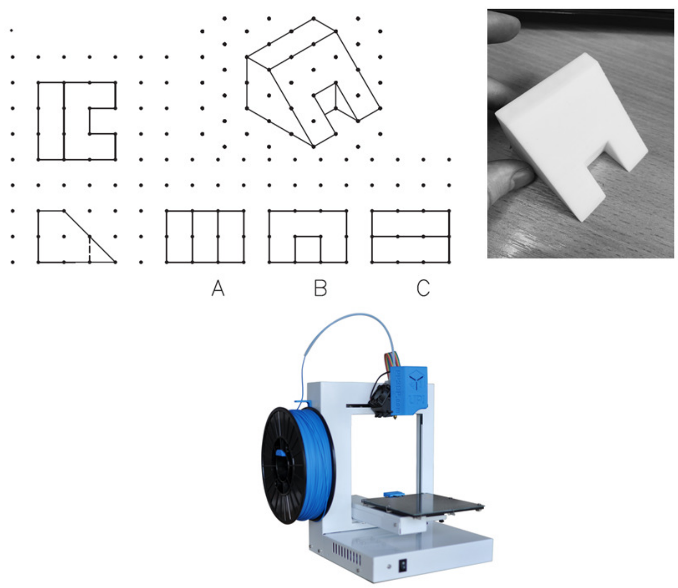

Figure 4 – Creating objects that typically cannot be formed using the snap-cubes

Each lab group consisted of 20 students with a range of spatial visualization abilities (Table 3). Rather than looking on this as a hindrance, we decided to empower students in various ways. An example of this can be explained through the revolving activity shown in Figure 5. Rather than solely converging on the solution (which is B), students were encouraged to discuss in pairs or groups why the other three options were incorrect. Students typically sketched the profile of the objects or created 3D models in SolidWorks.

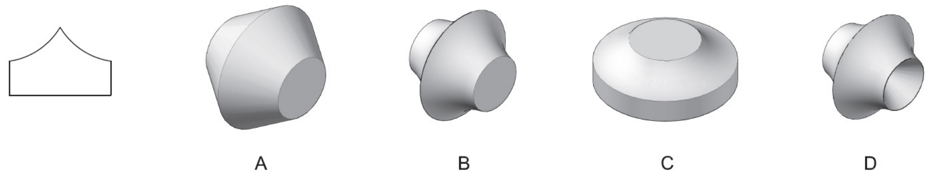

Figure 5 – Looking beyond the solution

We believe that the students were so engaged in looking beyond the solution because it not only helped them further develop their problem solving and spatial visualization but, they also appreciated the merits of the activities in helping them understand how other learners think about and comprehend visual information. The majority of students were very engaged and stimulated in working through the chapters as they saw this as not only a requirement of the course but also a skills building process in their journey towards becoming teachers of graphics at high school level. This is supported in some of the qualitative comments provided by students in their reflective diaries.

"I think my strengths lie within the Spatial Thinking labs because once I get a grasp of the concept in the workbook I find I fly through the questions. The course TA has us working in different groups throughout the labs and I find interacting with them helps us to wrap our heads around the task and helping each other understand where someone is getting a particular answer from." Student 2 (Female) – Pre-Test PSVT: R score of 70%.

"I sometimes get stuck doing questions in the spatial skills workbook but I find the group work in the Spatial Thinking labs very helpful in identifying the correct answer and understanding where that answer comes from." Student 88 (Male) – Pre-Test PSVT: R score of 73%.

"I think the Spatial Thinking labs are a great help. They really have helped me to understand the basics of technical graphics which I was lacking at the beginning of the semester." Student 51 (Female) – Pre-Test PSVT: R score of 33%.

Beyond the spatial thinking labs

In addition to the 2 hour spatial thinking lab, students completed 2 further lab hours each week that focused on solving various graphical tasks through the medium of freehand sketching and CAD, and they also had a 1 hour tutorial each week that focused on developing observational freehand sketching skills. Examples of some of the work produced by students in these classes are shown below in Figure 6 and Figure 7.

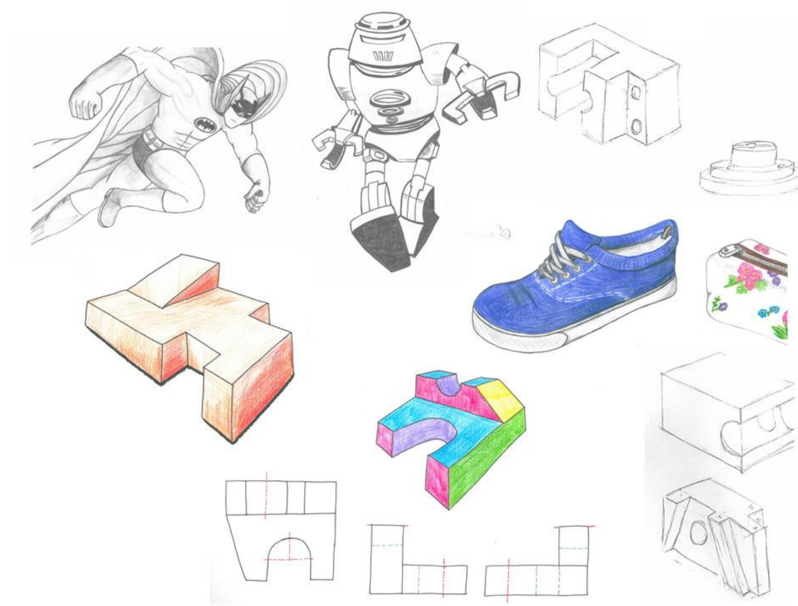

Figure 6 – Selection from a student's sketching portfolio for PN4011

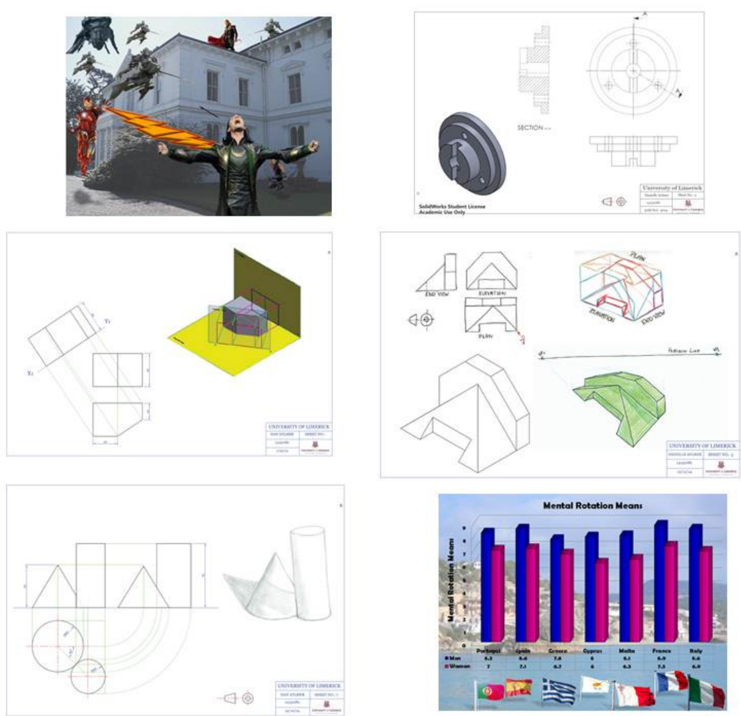

Figure 7 – Selection from a student's digital media portfolio for PN4011

Not only was it observed that students with below average spatial skills benefited significantly from this extra class time, we also found that those students with high spatial skills also valued the activities. This is supported in some of the comments extracted from students' reflective diaries:

"My strengths are the lab 1's, I enjoy these and have no issues as I work through the workbook. I also find my sketching a strong point as I am confident enough to try anything even if I make a mess of it ill still try again and give it another go." Student 8 (Male) – Pre-Test PSVT: R score of 97%.

"I have always achieved a high score in any special I have taken to date. This has shown me that special thinking is a strength that I hold and have found that sketching comes naturally to me also." Student 129 (Male) – Pre-Test PSVT: R score of 100%.

The Purdue Spatial Visualization Test of Rotations (PSVT:R) was administered to all students who were in attendance during the first and last lectures of the semester with a 12 week gap. 106 students completed both the pre and post-test. The data for the pre and post-test results are detailed in Table 4.

Table 4 – Pre and post-test results for PN4011

n	106
Pre-test (%)	69.4
Post-test (%)	83.7
Gain (%)	14.3
Sig. of Gain	$p < 0.0001$

A paired samples t-test was conducted to evaluate the impact of the intervention on students' scores on the Purdue Spatial Visualization Test of Rotations (PSVT:R). There was a statistically significant increase in PSVT: R scores from Pre-test (M = 69.4, SD = 15.74) to Post-test (M = 83.71, SD=13.45), $t(105)=12.83$, $p < .0001$ (two-tailed). The mean increase in PSVT:R scores was 14.31 with a 95% confidence interval ranging from 12.10 to 16.52. The eta squared statistic (.61) indicated a large effect size.

A selection of comments that were extracted from the reflective diary of one student is shown in Table 5. Student 68 had a Pre-Test PSVT: R score of 57% and Post-Test PSVT: R score of 97%. Considering the pre-test score, it is interesting that they perceived their spatial ability to be well developed based on their high school experiences. They continued with positive comments in their reflective diary throughout the semester but acknowledged that they actually got better with particular reference to the sense of enjoyment that they got from the activities in addition to commenting on the overall value that they credited to the spatial thinking labs.

Table 5 - Comments for Student 68 (Male) Pre-Test PSVT: R score of 57% and Post-Test PSVT: R score of 97%

Week 2	*"I find these tasks relatively easy as I feel I have the ability to think logically through these problems whilst having a clear visual image of the image/shape at all times. I noticed this a lot whilst doing subjects such as engineering for my leaving certificate."*
Week 7	*"I feel that I am doing ok. I think the Spatial Thinking workbook is after helping to develop my ability in Spatial Awareness. I find the AutoCad and SolidWorks very interesting and I am really enjoying working with them."*
Week 12	*"I think my spatial skills have come a long way since the beginning thanks to the lab 1's. I feel they are of great benefit to anybody who has not done DCG for leaving cert. I hope to further improve my sketching skills."*

Discussion / Conclusion

There are a number of positives that can be extracted from the study presented in this paper. A unique spatial skills intervention [8] was successfully blended into a freshman graphics course in an Initial Technology Teacher Education program at the University of Limerick. The spatial skills intervention was integrated into a unique set of learning outcomes that also included the development of observational freehand sketching skills and the ability to communicate graphically using digital media.

The level of improvement (Table 4) was very promising with a mean increase of 14.3% in the PSVT:R test. However, it is important to highlight that the post-test PSVT:R mean score of 83.7% (n=106) is only on a par with the average PSVT:R test score of engineering major students at Michigan Tech (83.3%) reported by Veurink & Sorby [4]. It should be noted that the nature of an engineering major versus a technology teacher major are somewhat different in nature, however they both have a commonality in that both sets of students are required to be graphically capable and have the ability to mentally manipulate and synthesize geometry.

Spatial ability is important across many fields of study including mathematics [10]. The students who were part of this study typically studied mathematics at one of two levels for the Leaving Certificate – Ordinary Level or Higher Level. 65 students studied mathematics at Higher Level where the mean score was within the 55-59% band width or grade C3. 56 students studied mathematics at Ordinary Level where the mean score was within the 80-84% band width or grade B1. These relatively low levels of mathematics preparation from Leaving Certificate could be further reason for the low scores in the PSVT: R during orientation.

It is worth looking back to the role of technology subjects in the Irish education second level (high school) system. As described earlier, there are a number of subjects at second level in Ireland that claim to promote the development of graphical capability. One of these subjects at senior cycle is Design and Communication Graphics (DCG). It was decided to analyze the group of students who took PN4011 to establish if there was any relationship between the pre and post PSVT: R score and if students took DCG at second level. This data are presented in Table 6.

Table 6 – Comparison of PSVT: R scores for students who did / did not take Design and Communication Graphics at second level

	N	Mean	Std. Deviation
Studied DCG (Pre-Test)	68	69.76	16.48
Studied DCG (Post-Test)	58	82.76	14.38
Did Not Study DCG (Pre-Test)	52	68.46	15.54
Did Not Study DCG (Post-Test)	50	84.5	12.79

A paired samples t-test was conducted to establish if the gains made by both groups were significant or not. There was a statistically significant increase in PSVT: R scores for both groups at the $p < .0001$ (two-tailed) level. The mean increase in PSVT: R scores for those students who had previously studied DCG was 12.53 with a 95% confidence interval ranging from 9.26 to 15.79. The mean increase in PSVT: R scores for those students who had not previously studied DCG was 16.46 with a 95% confidence interval ranging from 13.56 to 19.35.

It can be concluded from this data that students who studied DCG when they were in senior cycle did not have any advantage over students did not take DCG. In fact, students who did not take DCG at second level outperformed those who did in the post test. This raises question marks over the subject of Design and Communication Graphics at senior cycle in Irish second level schools. Is the subject effectively developing students spatial skills as outlined in the subject syllabus where one of the primary aims is *"to develop the capacity and ability of students in the area of visuo-spatial reasoning"* [11]. The summative examination (worth 60%) for DCG examines students' ability to solve problems in plane and descriptive geometry. Are students visualizing and reasoning through these problems or are they rote learning strategies to answer questions that are somewhat similar in nature each year? DCG students also complete a thematic design based project (worth 40%) through the media of freehand sketching and SolidWorks. It is possible that students may not be engaging in this project to a degree where their visuo-spatial skills and problem solving skills are being exercised and developed.

It is clear from this study that although the philosophy of the Irish education system appears sound, there is evidence that future research is necessary to establish what the underlying reasons are for Irish males and females underperforming in spatial skills tests and how these problems can be overcome. In moving forward, future research should consider examining the nature of what is occurring at second level in the Irish education system. Why are Irish males and females underperforming in spatial tests? Where do the problems lie and how can they be addressed? In terms of initial technology teacher education, future work will focus on further building student teachers visuo-spatial skills and graphical capability with specific focus on developing students ability to mentally section, manipulate and synthesize visual mental imagery.

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