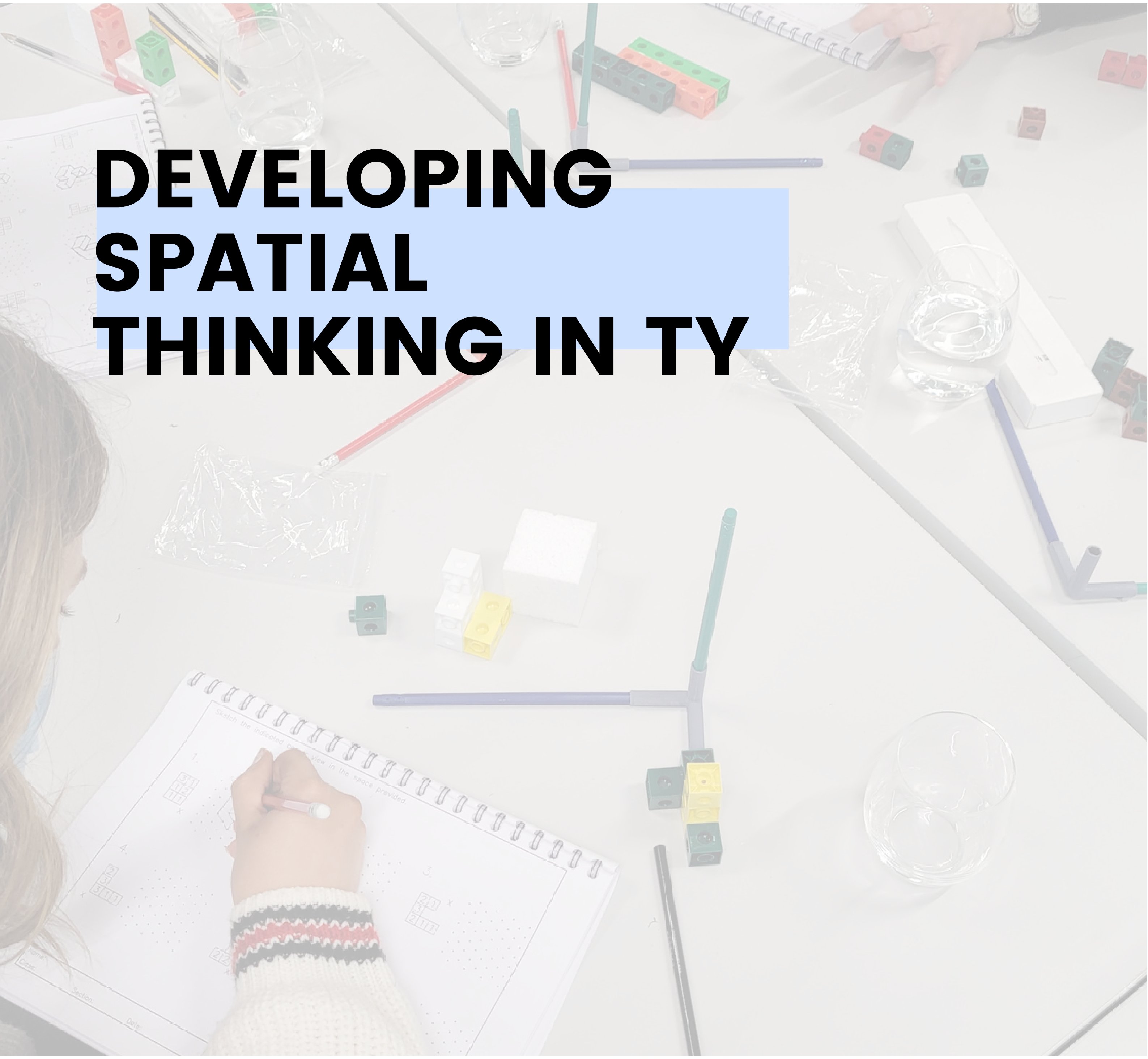


DEVELOPING SPATIAL THINKING IN TY

November 2023

Oide

TU Dublin, TUS, University of Cincinatti

C3S

INTRODUCTION

Spatial ability relates to the generation, storage, processing and manipulation of mental images. It is the ability to visualise something in the mind, manipulate that visualisation in some way such as rotating, mirroring or adding to it and making decisions about the new visualisation. Spatial ability is really a set of skills whose breadth in type and form make it difficult to describe succinctly. For over 100 years, spatial ability has been considered to be a primary factor of intelligence along with verbal and mathematical skills. Working memory consists of the visuospatial sketchpad, i.e. spatial ability, and the phonological or verbal loop. Key to the process of learning, working memory is notoriously limited in capacity – forgetting the key point of a class as attention becomes focused on other information is an example of working memory overload.

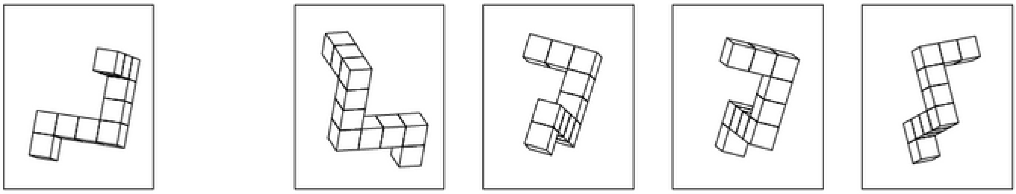
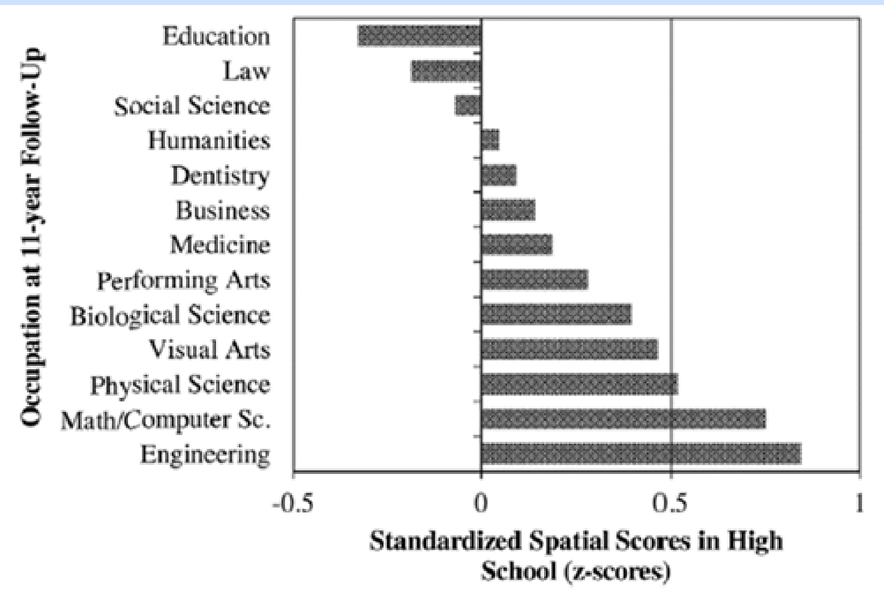


Figure 1. A mental rotation test. Two of the objects (1 and 3) are rotated versions of object on left, and two (2 and 4) are mirror images. The challenge is to select the rotated versions quickly - accuracy and speed are required for this.

Spatial ability is measured through psychometric tests, with different tests for different factors. One factor, speeded mental rotation, has been shown to be strongly associated with success in STEM. Spatial ability is linked to success in STEM in several ways – visualising molecular structures in chemistry, frame of reference motion problems in physics, developing algorithms in computer programming, and mentally representing word problem scenarios in mathematics and other subjects – all these tasks require spatial visualisations of some form that unlock a key step in the learning process. Spatial ability is also linked to creativity and innovation in STEM. This report provides an evaluation of a course on Developing Spatial Thinking that was delivered to TY students over several weeks.

In Project Talent, psychometric data were collected from 50,000 boys and 50,000 girls in each of the four years of high school in the U.S. Participants were contacted 11 years later to find out what education and career choices they had made. Shown here are there spatial ability scores measured in high school but grouped by chosen occupation 11 years later. In predicting STEM choices, spatial ability was found to be more discriminating than verbal and even mathematical abilities.



GENDER & SES

There are significant gender differences in 3D spatial skills favouring males. This is not the case for all factors of spatial ability; however, there is typically a male advantage in speeded mental rotation, a factor of spatial ability that is very important in STEM learning. Research shows that:

- **students from low socioeconomic status (SES) groups also have comparatively weak spatial skills.**
- **SES differences can be larger than gender differences.**

It has been shown that the reason some groups (i.e., females and low SES) tend to have low spatial skills compared to their more affluent male peers:

- **May be related to the type of toys they played with and activities they engaged in as children.**
- **University students with high spatial ability tended to play with Legos, take shop or mechanics classes, fix and put together things like bicycles, or play certain shoot 'em-up computer games during their formative school years.**

Previous research found that delivering the Developing Spatial Thinking course to Engineering students:

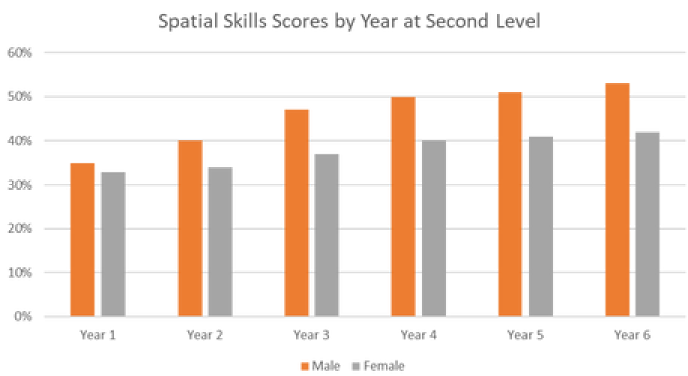
- **led to gains in spatial ability for males and females**
- **females achieved higher gains**
- **females achieved higher grades in their engineering courses and higher rates of graduation**

Changing current or cultural norms where boys are encouraged to play with Legos and girls to play with dolls, is beyond the scope of any one educational project. Providing *all* students with experiences explicitly aimed at improving their spatial skills at an early age will help overcome deficits due to culture and not due to ability.

Raising spatial ability levels of children, especially girls and children of low SES, will improve diversity and representation in STEM classes, particularly those areas such as engineering and computing that are significantly underrepresented by females.

Gender and SES differences in spaital ability limit success in STEM for many children

IRISH CONTEXT



Data collected in 2017 from 4509 students in all six years of secondary school in Ireland revealed that boys and girls begin secondary school with nearly equal levels of spatial ability but a gap in favour of boys grows steadily from 2nd to 6th year. Ireland is not unique in this regard as data from PISA 2012 have shown, but several countries have shown that a gender gap can be prevented. Action can be taken in Ireland to at least reduce, if not eliminate completely, this gender gap in spatial ability.

The performance of Irish students on PISA is relatively good – Ireland was ranked 17th among 37 OECD countries, and 11th out of 28 EU countries in PISA 2018 in both science and mathematics (McKeown et al., n.d.).

However, when spatial thinking was assessed as one of four mathematics components in 2012, Ireland's performance was very poor and dragged down the overall PISA mathematics score that year (Thomson et al., 2013).

This suggests that Ireland could improve its ranking even more by just addressing a deficit in spatial ability. We know from numerous research studies that a deficit in spatial skills will inhibit learning and limit performance in several key aspects of STEM. Ireland is performing well in PISA; improvements in spatial ability will help to improve our standing.

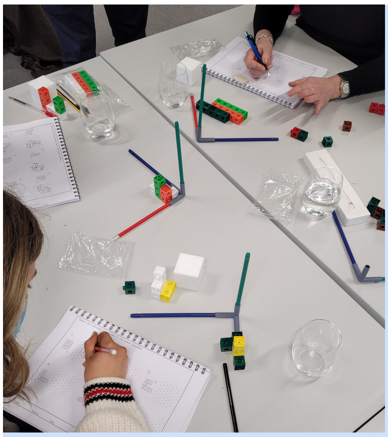
PISA Math sub scale	Ranking of Ireland	Mean score of Ireland
Change and relationships subscale	20	501
Space and shape subscale	34	478
Quality subscale	19	505
Uncertainty and data subscale	17	509

The STEM policy document contains noble ambitions for increasing enrolment in STEM courses in Ireland in the coming years and many great initiatives are underway to make this happen. Raising the spatial ability levels of boys and girls will complement these efforts at a more foundational level by addressing a particular cognitive ability that is highly correlated with success in STEM but whose development is not explicitly nurtured but is often left to chance. Many Irish children have untapped potential in spatial ability and STEM. Providing these children with opportunities to develop spatial ability will prepare them for the many cognitive demands of STEM learning and help Ireland fulfil its STEM education implementation plan.

ADAPTED FOR TY

Researchers from TU Dublin, TUS and the University of Cincinnati worked with staff from PDST and subsequently from Oide to adapt the existing Developing Spatial Thinking course for TY students. A small preliminary field study was conducted in March - April 2022 in which 5 schools with 10 teachers and 245 students delivered 4 modules over 6 weeks. This revealed the time and resources required to deliver each module.

A larger pilot study ran from **September 2023 to January 2024 in 25 schools with 48 teachers and circa 2,000 students (data from 1199 students are included in the analysis)**. Teachers attended 3 PD days, kept class logs, were interviewed during the term and completed spatial tests. Students were tested for spatial and maths ability before and after completing the term. An exit meeting was held with teachers to gather lessons learned and a Shared Learning Day was held in May 2023.



Professional Development

- 3 full day workshops at TUS
- Attended by 48 maths teachers
- Spatial testing
- 6 different modules covered
- Use of manipulatives
- Use of supporting software

Course Delivery

- Pre-test spatial and maths ability
- 6 modules delivered from Sept. to Dec.
- 2 to 4 classes per week instead of maths
- Experimental group took the spatial course
- Control group took normal TY maths classes

Participants

- 25 schools, 20 Coed, 4 all girls, 1 all boys, 8 of which are DEIS,
- 1,199 TY students, 488 boys, 711 girls
- 13 counties, all 4 provinces
- 786 experimental, 413 control

THE SPATIAL COURSE

The DST course has been running now for 30 years and has been used in secondary schools and universities in the U. S. It is very hands on - topics are introduced quickly through video and software. Students quickly progress to sketching in the workbook assisted by snap cubes and axes to scaffold visualisations. A randomized trial showed the course leads to significant increases in spatial ability for those who take it. It has also been shown to benefit student performance in other subjects including mathematics. Girls with initially low levels of spatial ability have been shown to gain a lot of benefits from taking this course in terms of improved performance in other subjects and increased graduation rates in engineering.

Oide

Project management, classroom visits, PD days, staff time, teacher release time, materials

TU Dublin, SellSTEM

Research the intervention from the teacher perpsctive

TUS: Midlands, Midwest

Research the intervention from the student perpsctive

University of Cincinatti

Steer localisation of the intervention

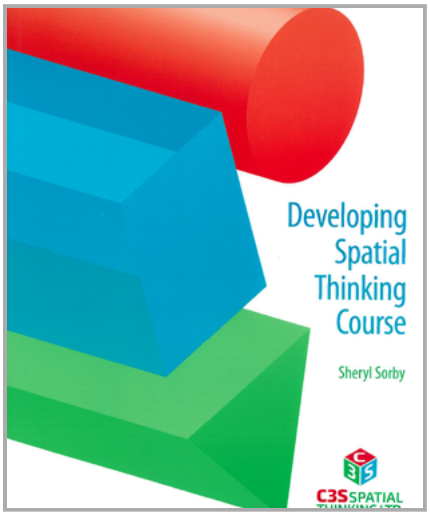
C3S

Supply workbooks and manipulatives

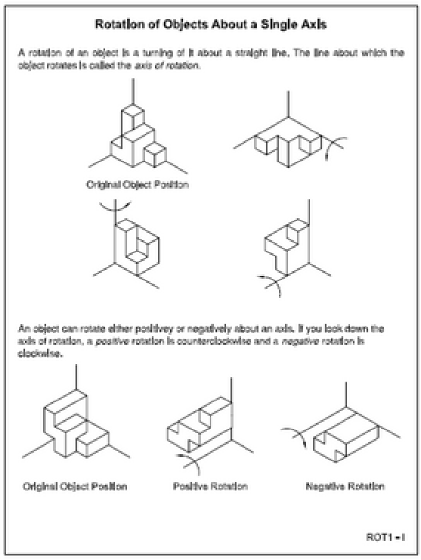
Schools

25 schools, 48 teachers, circa 2,000 students

Experimental and control groups



Over 10 modules, the workbook covers a range of spatial tasks: nets, isometrics, combining objects rotating around 1, 2, or 3 axes, mental cutting, orthographics and symmetry. The sketching tasks are challenging and are supported by snap cubes and axes. These allow students to create external visualizations to scaffold thinking.



Rotation of Objects About a Single Axis

A rotation of an object is a turning of it about a straight line. The line about which the object rotates is called the *axis of rotation*.

Original Object Position

An object can rotate either positivey or negatively about an axis. If you look down the axis of rotation, a *positive rotation* is counterclockwise and a *negative rotation* is clockwise.

Original Object Position | Positive Rotation | Negative Rotation

ROT1 - I

Research Study

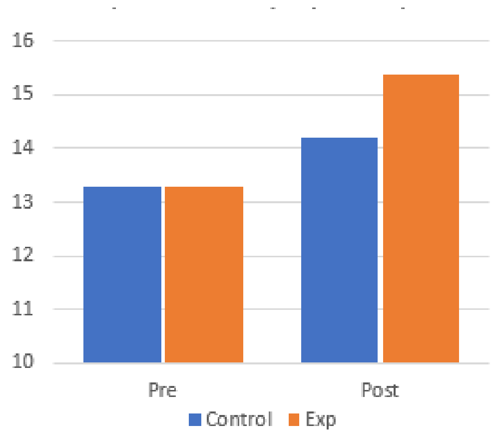
- Does the course lead to gains in spatial ability for the students?
- What, if any, impact does the course have on maths ability?
- How do gains vary by gender and SES?
- How well designed is the PD programme for teachers?
- How did the teachers experience delivering the course and what impact did it have on their spaital ability and approach to teaching maths?

Ethical approval was obtained from TUS.

Impact on Students

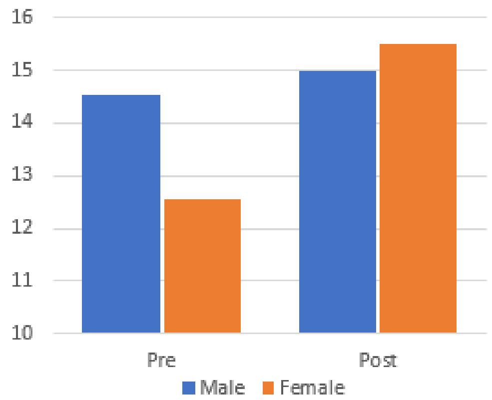
✓ Spatial ability increased

Those who completed the course (experimental group) scored significantly higher on the second spatial test than those in the control group who didn't complete the course. This result was obtained after controlling for initial level of spatial and mathematical abilities so we are very confident the difference is due to the delivery of the course rather than the selection of the students.



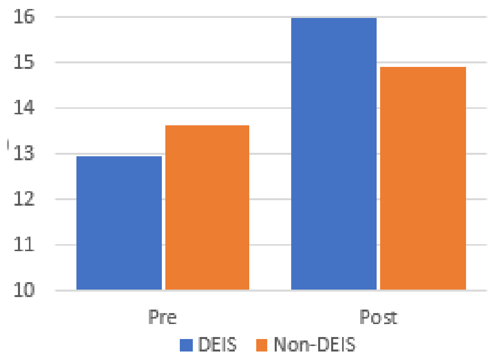
✓ Gender gap removed

Before the course, boys had significantly higher levels of spatial ability than girls but no significant difference was measured after the course. Girls and boys ended with similar levels of spatial ability. Closing the gender gap in spatial ability was a major objective of this intervention.



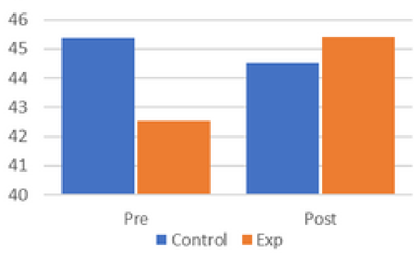
✓ SES difference upended

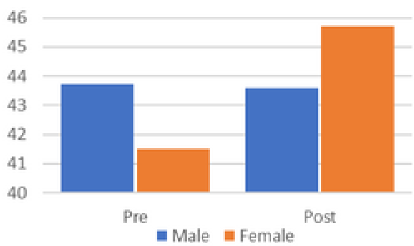
Students from DEIS and non-DEIS schools had similar levels of spatial ability before the course. After the course, students from DEIS schools scored significantly higher on spatial ability than non-DEIS students. Spatial ability typically increases with SES so this is an unexpected finding.

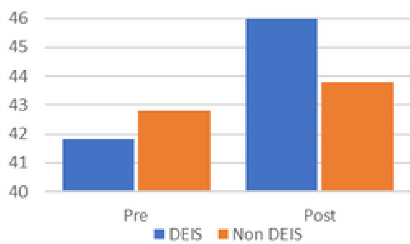


✓ Transfer to mathematical ability

Mathematical ability was tested using the PDST math competency test. The experimental group achieved a higher score on the maths post-test than the control group even though they started out behind! From initially scoring lower than males, females outperformed males on the maths post-test. DEIS students also experienced much higher gains in maths than non-DEIS students.







Impact on Teachers

Effective PD developed

Delivered over 3 separate days, the PD structure was highly praised by the teachers. Discussing, sharing ideas and difficulties with other teachers, the blended delivery, going through the workbook, having the manipulatives were all good features of PD. A very effective PD programme is now in place for this course.

From apprehensive to confident

Many teachers were very apprehensive about teaching the course. This moved them out of their comfort zones and, for many, opened up a much more collaborative way of working with students. “We’re all in this together!” Teachers overcame the challenge of teaching a new topic and all were able to deliver the course successfully. They ‘enjoyed’ delivering the course. Almost all schools signed up to participate again. Those teaching it a second time found their confidence had improved substantially.

TY routine is variable

The sometimes-disjointed nature of TY created challenges for teachers. Students became separated in progress with some ahead, some behind. The absence of a formal assessment devalued the course for some.

Benefits to students

Teachers reported how students engaged well with the course, the hands-on activities and the software. Some students who were “not good at maths, it clicked with them”. Students were excited it was something different. It gave structure to TY maths. They enjoyed building shapes and showed more enthusiasm towards maths. Students who had done T4 subjects excelled – the difference was noticeable.

Lessons learned

The vast majority of schools have signed up to run it again as they really liked teaching it. Next time, they will make connections to the LC syllabus - for example transformations & trigonometry. Some will spread it out over the year. Extra content is being developed to support the varying rates of progress. A project element with assessment is being explored.

NEXT STEPS

The successful delivery and evaluation of this intervention is the result of an international, interdisciplinary and intersectoral collaboration between researchers, experts in teacher PD and TY teachers. Based on the research findings gathered from student and teacher participants, several future directions for action and research have been identified.

No. 01 – Expand PD to reach more teachers

Investigate ways to use virtual learning to facilitate the PD process and effectively prepare teachers to deliver the intervention. Explore a blended and regional approach to delivery of the professional development programme.

No. 02 – Transfer to maths ability

Research is needed to examine the mechanisms by which the intervention improves maths performance. The types of maths skills that are improved are of particular interest.

No. 03 – Longitudinal study of student impact

The long term impact of the intervention on students in terms of attraction towards and performance in STEM education is currently unknown. A longitudinal study in which Leaving Cert grades or other measures of academic performance are collected will help answer this question

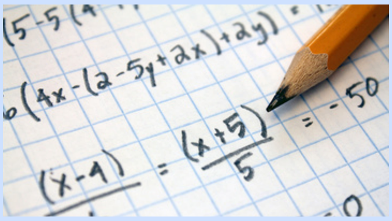
No. 04 – Integration with other subjects

Additional activities to provide students with additional challenges in the spatial domain could be developed. These could also faciliate integration with other STEM subjects and could also introduce students to a range of STEM career paths.

CONCLUSIONS

A programme aimed at improving the spatial skills of *all* students was pilot tested in TY maths classes during the 2022-23 school year. Results from the pilot test are promising- gender and SES gaps were eliminated and transfer to maths achievement was observed. Planned revisions to the programme will make it more accessible for more teachers (and their students!) and easier to implement.

- Gender differences in spatial skills were eliminated.
- DEIS differences in spatial skills were eliminated.



- Maths scores in the Experimental Group increased
- Despite receiving more *direct* maths instruction, maths scores for students in the Control Group decreased slightly.

- Teachers were enthusiastic about teaching the spatial modules
- Teacher confidence improved with practice

Acknowledgements

We gratefully acknowledge all the teachers and students who participated in this pilot study and the school principals and managers who gave their support. We thank TUS, TU Dublin, the PDST, and Oide for providing facilities and resources for the PD programme. This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956124 (sellstem.eu) and the TUS postgraduate research scholarship scheme.

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