AN ONGOING SPATIAL INTERVENTION PROJECT IN IRISH SECONDARY SCHOOLS FOR IMPROVED ENGINEERING EDUCATION

RESEARCH PAPER

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ABSTRACT

Spatial skills have been shown to strongly predict STEM attainment and can therefore be a determining factor in choosing to pursue high-paying engineering careers. This strong reliance on them particularly limits students with low spatial skills – a group over-represented by girls and students of low socioeconomic status. It has also been demonstrated that spatial training leads to meaningful improvements in skill development. In Ireland, as in most countries, spatial thinking is not explicitly taught at the pre-college level, even though it could influence students' eventual career paths. Currently, only a person's previous experiences outside the classroom influence skill development. In order to increase the number of students who select engineering and other STEM occupations as a career path, an explicit emphasis on training spatial thinking is likely to be very beneficial in pre-college education. An established spatial intervention course was selected for delivery to secondary schools in Ireland. Through training and ongoing support, teachers' spatial skills, and pedagogical content knowledge for spatial thinking are being developed to be shared with their students, leading to an increase in students' spatial skill level and future employment opportunities.

1 SPATIAL SKILLS

Spatial skills can be defined as spatial visualization, which includes the ability to imagine and mentally transform spatial information [3]. Wai, Lubinski, and Benbow [9] examined the importance of mathematical, verbal, and spatial skills in high school students using measures of spatial visualization and how they affected their later career choice and success in STEM fields. They analyzed the data from Project TALENT, which included students' assessments of cognitive skills (mathematical, verbal, and spatial skills) from the 9th until the 12th grade. The sample included approximately 50,000 males and 50,000 females per grade level. After 11 years, they gathered follow-up data and found that most STEM graduates came from the group of students whose spatial skills were highly developed at age 13. This skill has shown to be the best indicator for future STEM success (especially for engineering) – even more so than the level of mathematical and verbal development.

1.1 Spatial Intervention

Findings from large-scale studies such as Project TALENT highlight the need to investigate the extent to which spatial skills training can facilitate improvements in performance in a range of STEM tasks. Motivated to explore the connection between spatial skills and success in engineering majors, Sorby and Baartmans [8] developed a spatial visualization course for first-year engineering students, which emphasized sketching and interacting with 3D models of geometric forms. Their data showed the course developed students' spatial skills, which were correlated with improved performance in graphics courses and an increase in the engineering major's retention rate (especially for female students) [8]. These very encouraging results led to another three-year study conducted with middle school students which showed that students who took part in the training significantly improved their spatial skills compared to those who did not [7].

Spatial skills are a primary factor of intelligence that is viewed as a combination of several separately measurable subfactors. Some of these, mental rotation in particular, typically reveals gender differences in favor of males. Since mental rotation and related factors are so highly correlated with performance in many STEM tasks and girls are often under-represented in STEM courses, improving spatial skills might play a significant role in reducing this gap in representation. One interesting result that emerged from the middle school intervention study was that female participants who improved their spatial skills through the training subsequently enrolled in more math and science courses than girls in a similarly identified comparison group [7]. This could suggest that the training reduced their spatial and math anxiety levels. A study from 2019 [8] demonstrated that spatial anxiety relates to spatial strategy avoidance in solving mathematical problems which negatively influences math success, math anxiety and math avoidance. There is also some evidence that girls who perform lower in maths may be at higher risk for developing math anxiety than are similarly performing boys [1]. Therefore, systematic development of spatial skills in the education system is needed and can be successfully implemented with middle school students where it still influences their choice of high school subjects and future career opportunities.

1.2 Rationale for the Study in the Irish Context

Results from a recent national study in Ireland [5] highlight the underdevelopment of spatial skills in grade 7, which is the 1st year of post-primary students, and that a relatively small gap in spatial skills in favor of males exists at this stage but grows quite significantly over the subsequent years in the second level through to grade 12. Also, the Irish STEM Education Policy Statement 2017–2026 emphasized the necessity to ensure that students' learning in STEM disciplines significantly improves and that more young people (especially females) choose and sustain their involvement in STEM education. To accomplish this goal, continuous efforts in initial Teacher Education and teachers' ongoing professional development (PD) are needed [2]. Since the Developing Spatial Thinking course yielded positive effects on middle school students' subject choice and STEM engagement, it has been chosen to be adapted for the Irish transition year (TY) students aged ~ 15 years.

2 METHODOLOGY

The purpose of the current small-scale pilot study is to test a project plan and research design that will be refined and used in a large-scale pilot study that will commence in September 2022 involving approximately 60 teachers in several secondary schools in Ireland. The data for the entire project are being collected from students and teachers – focusing on teachers' needs and requirements, and how to design the professional development (PD) to address these. The project is being designed and delivered in collaboration with the national in-service teacher training organization in Ireland, Professional Development Service for Teachers (PDST). After 2 years of gathering and analyzing teacher and student data on the effects and the structure of the intervention, the course and the PD will be refined and implemented on a national scale for the TY students.

2.1 Participants

Schools were canvassed by the PDST for interest in participating in the project and a small number of these schools were approached for participation in the small-scale pilot project. A total of 10 teachers were recruited as shown in Fig 1. One teacher did not complete the post-test and the post-interview, so their data cannot be included in the final pre- and post-differences examination process.

Participants	SMALL-scale pilot study 2021/22	LARGE-scale pilot study 2022/23
maths teachers	10	~ 40
TY students	~ 250	~ 1000

Fig. 1. *The small-scale pilot and large-scale pilot study participants.*

All participating teachers teach mathematics in grade 9 which is called transition year (TY) in the Irish school system. This is the year in which students undertake a wide variety of non-academic activities such as work experience and community care. However, much of their time is spent in school which gives teachers the flexibility in their timetable to trial novel educational experiences and interventions.

Description of the Spatial Course

The spatial course comprises 10 modules:

1. Surfaces and Solids of Revolution
2. Combining Solids
3. Isometric Sketching and Coded Plans*
4. Orthographic Projection*
5. Inclined and Curved Surfaces
6. Flat Patterns
7. Rotation of Objects about a Single Axis*
8. Rotation of Objects about Two or More Axes*
9. Reflection and Symmetry
10. Cutting Planes and Cross Sections

The four modules (marked with an asterisk) focus on developing students' sketching skills with the use of manipulatives (snap cubes). They require students to build a shape and sketch it from different perspectives. The importance of hands-on experiences for learning originates from Piaget's theory of cognitive development [4]. His theory claims that students need physical references to understand mathematical concepts, hence this element is an important feature of the course. In addition, sketches provide external representations of the visualizations formed by students which can then be examined and reflected on to check for accuracy and provide feedback on how they are visualizing. For this study, a website with online resources for individual modules was created, that includes:

- brief lectures with video demonstrations,
- interactive software,
- supplementary online teacher resources, and
- optional videos with additional exercises.

Physical workbooks with sketching exercises for each module were prepared for students. Teacher guides with lesson plans and pedagogical implications were arranged for teachers. Provided materials for fostering hands-on learning included:

- snap cubes to build and manipulate 3D shapes, and
- K'nex to represent the x, y, and z axes for demonstrating the rotation of objects around one or multiple axes.

2.2 Project Overview

The entire spatial project consists of three major steps. The first step (in the academic year 2021/22) is devoted to the small-scale pilot study, the second to the large-scale pilot study (the year 2022/23), and the third (from 2023/24) to the implementation of the spatial course in the transition year curriculum as shown in Fig. 2.

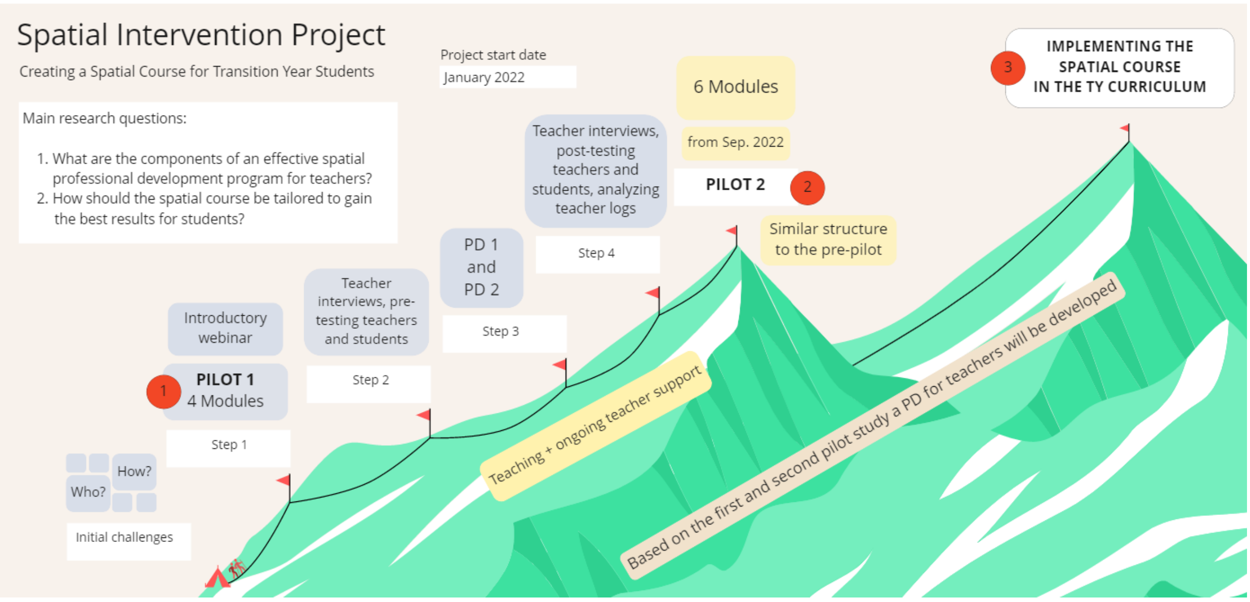

Fig. 2. *The structure of the Spatial Intervention Project: small-scale pilot, large-scale pilot study, and the nationwide implementation in the TY curriculum.*

Small-scale pilot structure

In January 2022, the small-scale pilot began. The initial challenges revolved around selecting which schools and how many teachers of which subject were going to be involved, which modules from the spatial course were going to be taught and how the entire process of the intervention was going to be organized. The purpose of the small-scale pilot was to assess all instruments and the quality of the PD for teachers to refine them and use them on a larger scale during the second pilot study.

Step 1 included the decision on which modules will be taught and the introduction of the study with the whole timeframe to the participants (teachers).

Step 2 describes the activities between the initial introduction and the first professional development day. Teachers were asked to take part in a pre-intervention interview where the researcher asked questions about their perception of spatial skills within the curriculum and their expectations of the spatial training. Teachers signed the consent forms for participation and completed the spatial test (PSVT: R Visualization of Rotations Test) with the incorporated feedback questionnaire on their experience of solving spatial tasks. Also, students were given the PSVT: R test to assess their skill level prior to the intervention.

Step 3 combines the two separately performed professional development days. The first one created a safe space for teachers from different schools to get to know each other and explore the fundamental module 3 (Isometric Sketching and Coded Plans) and module 7 (Rotation of Objects about a Single Axis) with an emphasis on pedagogy and on their content knowledge development through hands-on manipulation and sketching activities in student workbooks. After that, they started teaching the modules in their classroom. The second PD occurred a month after the first. Teachers shared their experiences of introducing the spatial course to their students and the students' initial reactions to the spatial tasks. During the PD, they worked on module 6 (Flat Patterns) and module 8 (Rotation of Objects about Two or More Axis), again with the emphasis on pedagogy and the use of multiple manipulatives.

The professional development days centered on fostering teachers' pedagogical content knowledge by improving their understanding of the skills' importance in STEM, and their skill level, and actively exploring ways of supporting their students in the future. Examples of student support discussed during the PD are:

- Use concrete examples to explain the isometric view by observing the corner of the room from different perspectives.
- Use the manipulatives (snap cubes, K'nex). Students who struggle must build the shapes first before sketching them. Start with the easiest examples and

give them time to explore the materials. Make sure they understand the isometric sketching and coded plans of module 3 before moving on.
- Students can cut out different shapes and fold them to get a better understanding of where the edges align.
- Make use of the online resources. Students can watch the videos and build along, solve additional examples and work with the interactive software.

While teachers were teaching the course, classroom observations and ongoing support were provided by the PDST. Teachers were also required to fill in a teacher log document after each lesson to reflect on their experience.

Step 4 describes the current and final stage of the small-scale pilot study. The researcher will conduct another set of teacher interviews regarding the implementation process, their recommendations for improvement, and their overall experience of teaching the course. The teacher logs will be collected for further analysis, and spatial tests will be given to teachers and students to measure the effects of the course on their skill development. Teachers will also answer questions on the questionnaire regarding their experience taking the test to compare the results with the first set of tests.

3 RESULTS AND DISCUSSION

The initial teacher pre-test spatial scores presented in the left graph in Fig. 3. show that the teachers' spatial skills before the intervention were relatively good. Seven participants out of nine scored from 65 % to 95 %. When observing their perceived difficulty level (from *very, very easy = 1*, until *very, very difficult = 9*) it is revealed that they all experienced it as difficult (*6 = rather difficult*, *7 = difficult*, and *8 = very difficult*), regardless of their skill level. An explanation for this could be the unfamiliarity with the spatial tasks. Perceived difficulty can influence teachers in spatial skill avoidance, where they are not actively seeking ways of incorporating it into their teaching. This provides a strong incentive to organize an effective PD to familiarize them with spatial activities and assessments with the goal of reducing the perceived difficulty level.

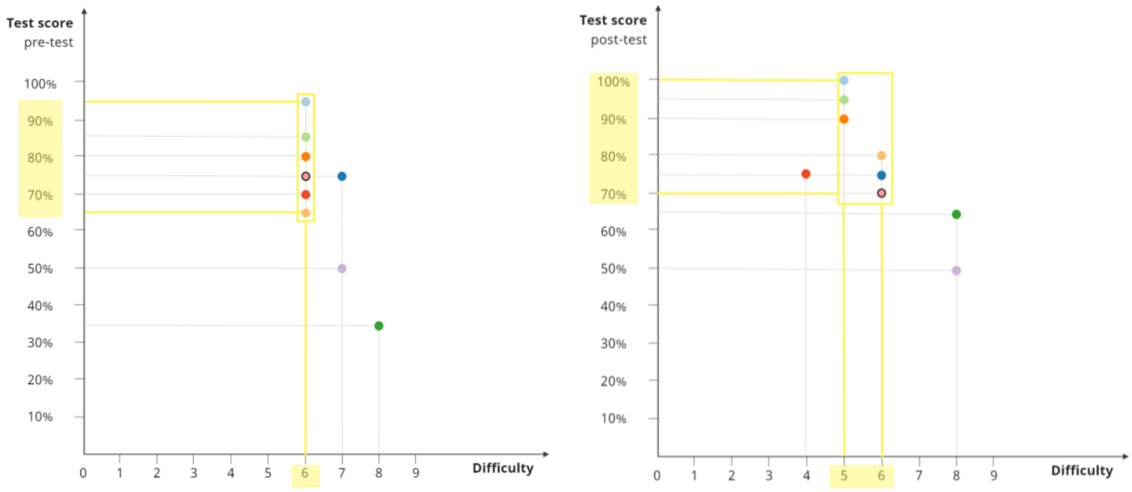

Fig. 3. *The pre- and post-test results with the perceived difficulty level.*

The right graph in Fig. 3. shows the post-test results and perceived difficulty level after the spatial PD. The majority scored from 70 % to 100 % and experienced the difficulty levels 5 (neither easy nor difficult) and 6 (rather difficult). One teacher experienced it as rather easy (difficulty level 4), and two as very difficult (difficulty level 8). Four teachers (presented in colors: light blue, light green, dark orange, and red) improved their test scores and felt it to be less difficult compared to their pre-test experience. Two teachers (dark green and light orange) improved their test scores but experienced the post-test to be as difficult as the pre-test. Two teachers (purple and dark blue) received the same score but experienced a difference in the difficulty level. The first one (purple) experienced the post-test to be more difficult and the second one (dark blue) as less difficult than the pre-test. One teacher (light pink with a black circle) received a lower score on the post-test and experienced it to be as difficult as the pre-test. During the post-interview, it was discovered that this teacher took the time to focus on the pre-test but rushed through the post-test due to personal time restraints. Based on the teachers' pre- and post-test scores we can observe a general increase in their spatial skill development and a decrease in perceived difficulty level. This suggests that direct training of the skill through the spatial course and having the opportunity of teaching it to students can improve their skill and confidence level in teaching it.

Pre- and post-intervention teacher interviews are currently being analyzed and will be presented in the future. So far, they reflect the potential of this spatial intervention in secondary education based on teachers' experience of the small-scale pilot study. Teachers generally felt their spatial skills improved and gained a better understanding of how to develop them in their students – suggesting an improved pedagogical content knowledge for spatial thinking. It will be interesting to compare the effects of the small- and large-scale pilot study to find if these benefits improve with longer exposure to the intervention.

4 SUMMARY

Spatial skills have been linked to success in engineering. Since they are currently not being systematically developed in Irish pre-tertiary education, their development is being left to chance. Students with better developed spatial skills tend to choose more math and science subjects, which affects their career opportunities. To increase the number of students who could engage in engineering, a spatial intervention in Irish secondary schools is needed. The small-scale pilot study included teachers who wished to incorporate spatial skills in their lessons but needed guidance and support in the form of professional development to accomplish this goal. So far, the training proved to be beneficial in improving teachers' spatial skills and reducing the experienced difficulty level when working with spatial problems on the test. Through a small-scale and a large-scale pilot study, data on the quality of the PD for teachers and the effects of the spatial course on students will be gathered and used to improve it. Future work in Ireland will involve the implementation of the refined spatial intervention in transition years.

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