The challenges of implementing a spatial ability intervention at secondary level

Liam Maquet, Technological University of the Shannon
Contact email - Liam.maquet@ul.ie
Urša Benedičič, Technological University Dublin
Rónán Dunbar, Technological University of the Shannon
Jeffrey Buckley, Technological University of the Shannon
Gavin Duffy, Technological University Dublin
Sheryl Sorby, University of Cincinnati

ABSTRACT

Spatial skills development has been widely examined throughout the literature, with evidence suggesting many cognitive abilities are malleable and can be improved through targeted solutions. Some previous examples of intervention studies have been shown to reduce the gap between genders, and those of a lower socio-economic status where the training increased spatial ability, as well as in discipline-specific educational performance. These findings align with many national agendas for STEM diversity, which strive to increase participation and performance of such under-represented groups in STEM.

With a lot of research being conducted around spatial skill development within a university level setting, or outside of a formal educational context completely, the applicability of such training interventions in a secondary level school context is unclear. With secondary level education aiming to develop many cognitive abilities, including spatial ability as outlined in curriculum documents, the implementation of such an intervention could improve student outcomes and add value to the educational experience of the students. With the time-sensitive nature of secondary level schooling, there are many concerns around the amount of time and effort that needs to be invested to successfully implement such an intervention. Through the piloting of a spatial training intervention, this paper focusses on the development of spatial skills within an upper secondary level setting in Ireland with 358 students aged 14-16 enrolled in the Transition Year programme and their 10 teachers.

This paper examines the challenges of implementation of a specific spatial skills intervention, through a variety of lenses, including pedagogy based and performance based, and offers considerations for future research in the area. By looking from both teacher and student perspectives, we explore the issues encountered and offer suggestions to researchers conducting similar studies at secondary level.

Key Words: Cognitive training, secondary level, intervention, student gains, teacher views

1. INTRODUCTION & LITERATURE REVIEW

1.1. Spatial Ability

Cognitive abilities play an important role in developing someone's ability to acquire, process and apply new knowledge (Kautz et al., 2014) and consequently engage in critical thinking (Duffy, 2017). One such ability is that of spatial ability. Spatial ability has gained increasing attention due to its importance in various STEM disciplines (Wai et al., 2009) and real-world applications (Newcombe, 2010), with spatial ability being found as a predictor for participation and success in STEM fields later in life (Uttal et al., 2013). Defining spatial ability is a topic of contention (Uttal et al., 2013) but Buckley et al. (2018) offers an empirical definition based on the CHC theory of intelligence (Schneider & McGrew, 2012). Within this definition, there is the description of various factors within spatial ability itself, including that of visualisation for which there is an evidence base indicating that it is influential of student learning in technology education (Buckley, Seery, Canty, et al., 2018). The recognised importance of spatial skills in technology education is not a new idea and can be seen as an explicit part of Irish curricula (NCCA, 2019). In spite of its clear importance for students' academic success and career choice (Uttal et al., 2013), such abilities are currently underdeveloped in Irish secondary schools (Bowe et al., 2016) and therefore must be further developed with that age group. Technology education especially can be supported by the development of spatial skills, as the subject area demands such abilities within the students. Tasks specific to technology education such as visualising design solutions that do not yet exist, creating and interpreting working drawings, and understanding complex mechanical relationships require such skills. The malleability of spatial skills is known (Uttal et al., 2013), yet the best way to do this is still unclear. Newcombe (2017), when looking at a broader STEM level, proposed two strategies for raising the level of spatial ability. Strategy one focuses on direct training by providing specialized spatial courses to target the skill development. Strategy two however proposes spatialising the curriculum itself by incorporating spatial language, maps, diagrams, graphs, analogical comparison, physical activity that embodies scientific or mathematical principles, gestures, and sketching into teaching.

This study aims to describe and evaluate the process of implementing a spatial ability intervention in secondary level in Ireland. The intervention started in the academic year 2021/2022 when Technological University of the Shannon: Midlands Midwest (TUS), Technological University Dublin (TUD), University of Cincinnati, and the Professional Development Service for Teachers (PDST) collaborated to pilot a spatial professional development program (PDP) for secondary school mathematics teachers. The focus on mathematics teachers is driven by the fact that the PDST took control of recruiting the participants, however the program is appropriate for other secondary school teachers as well as the intervention itself is removed from subject context. The future implications for technology education can already be seen through the tasks being closely related to the skills used in technology education. Examples of this content include orthographic projection, isometric sketching, and symmetry, which can be directly seen through the use of working drawings, design sketching, and functional or aesthetic design. The visualisation skills utilised are associated with the types of activity typical within the technology classroom, such as visualisation design solutions and creating and interpreting working drawings.

1.2. Designing a Professional Development Program

A study conducted in the U.S. identified three core features of PDP activities that have significant, positive effects on teachers' learning (Garet et al., 2001). First, an effective PDP should focus on content knowledge to improve and deepen teachers' academic subject knowledge. Second, it should provide opportunities for active learning to increase teachers' pedagogical knowledge by ensuring that teachers become engaged in a meaningful analysis of their own teaching and form a good understanding of how their students learn. Finally, it should ensure coherence with other learning activities by aligning them with teachers' goals and the official educational standards. The duration of a PDP is also important. Longer activities (with a greater amount of contact hours) are more likely to provide opportunities for in-depth discussion of content, student conceptions and misconceptions, and pedagogical strategies. Activities that extend over a longer period are also more likely to allow teachers to try out new practices and receive constructive feedback (Darling-Hammond et al., 2017). In addition, the established learning environment should be (Bransford, J.D., Brown, A.L. & Cocking, R.R., eds., 2000):

- learner-centred, by acknowledging students' varied backgrounds, skills, experiences, interests.
- knowledge-centred,
- assessment-centred, to make students' learning visible, provide feedback and monitor their progress.
- community-centred, to develop norms in the classroom and connect them to the real world.

The implementation of interventions in educational settings can be quite diverse in nature, and as such there is no set guidelines on how this should be done. This paper aims to investigate the implementation of a specific spatial skills intervention and its associated PDP to identify challenges and opportunities for support in order to optimise future iterations of the programme.

2. METHOD

2.1. Approach and Participants

In Ireland, transition year (TY) and is an optional extra year between lower and upper secondary education. TY can be completed after the initial three years of secondary school (Junior Cycle) and before the final two years of secondary school (senior cycle), primarily focussing on extracurricular activities, and offering "pupils a broad educational experience with a view to the attainment of increased maturity, before proceeding to further study and/or vocational preparation" (NCCA, n.d., p. 2). A quasi-experimental study design was implemented to evaluate the impact on spatial skills of a spatial skills intervention. The study was conducted across a group of 358 TY students (aged 14-16) across Ireland in place of their usual mathematics classes. This sample size was determined by a process of convenience sampling, which was impacted by the recruitment process. The cohort included 152 male and 206 female student participants. Recruitment letters were distributed to schools by the PDST and expressions of interest were then collected from interested schools. Five schools were selected due to the available budget. The control group consisted of 120 participants and the experimental group consisted of 251 student participants (due to errors in filling out test information, while all student engaged with the study and its content, some students could not be assigned to a group for the purpose of data analysis, so their information was not included), with the control and experimental groupings being based on the pre-existing classes within each school. Along with the student participants, 10 teacher participants were recruited for this study but 1 of these later dropped out and was excluded from the analysis. These teachers engaged with a PDP based around the use of the spatial skills course, and the development of supportive pedagogical strategies.

2.2. Materials

The Purdue Spatial Visualisation Test: Rotations (PSVT:R) (Guay, 1976), Verbal Reasoning Test (VRT) (Ekstrom et al., 1976), and math test were administered to all student participants. The PSVT:R provided a measure of spatial rotations. The VRT was used as a control variable for the study by providing another measure of cognitive ability, while the math competency test provided a measure of math ability. All participants completed pre-testing before taking part in the intervention, and post-testing after completing the intervention. All testing was completed on a pen-and-paper basis. Participants were given time limits for each test as follows; 30 minutes for the PSVT:R, 15 minutes for the VRT, and 15 minutes for the Maths Test. Each participant completed the tests individually and under the supervision of the teacher, who reinforced the time limits.

The teacher participants then completed a spatial ability test with an included anxiety test when solving spatial problems. Teachers were also interviewed prior to the first professional development day and once again after they stopped teaching the course. During their teaching they completed short reflective teacher logs after each lesson to assess the quality of the lesson and think of possible improvements. Teacher logs were included in the teacher guide which made it easier for them to fill put since all teachers provided the completed pages at the end of the intervention.

The spatial intervention used was originally developed by Prof. Shery Sorby (Sorby & Baartmans, 2000) for use with third level engineering students, so another aspect of this study is to examine the suitability of the course content for secondary level. It involves 10 modules focussing on different aspects of spatial thinking. It includes modules based on the development of plan views, surface development, rotation of 3D objects about axes, reflection of 3D objects, and more. Although 10 modules are included in this course, only 4 were completed by the students as part of this study. This was determined by the researchers as a sufficient number of modules to complete within the time allocated, that was also provide an adequate indication of success. The modules completed were: *Isometric sketching and coded plans, Flat Patterns, Rotation of objects about a single axis, and Rotation of objects about two or more axes*.

During the intervention, each participant in the experimental group was provided with a physical workbook (Fig .1), snap cubes (Fig .2), and access to a website with interactive software (Fig .3). These resources were utilised throughout the intervention with the teacher in each classroom designing lesson plans for their own lessons. The control group did not engage with the intervention whatsoever and they continued with normal schooling.

Figure 1.
Workbook

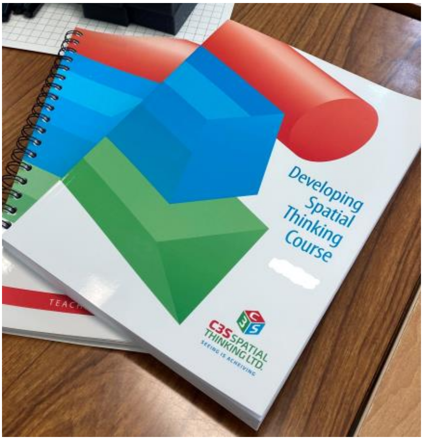


Figure 2.
Snap cubes (a physical manipulative to aid the visualisation of complex geometry)

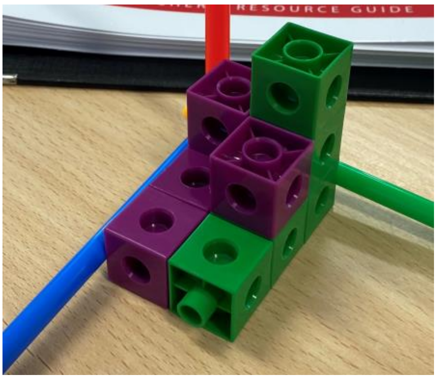
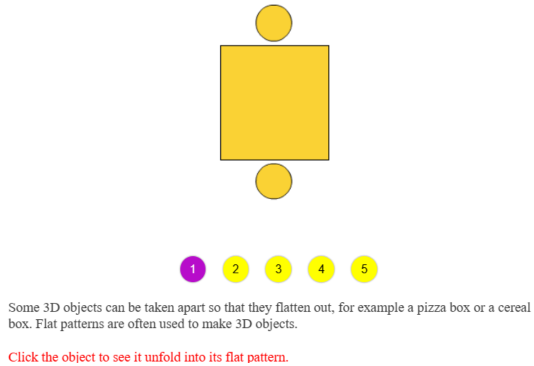


Figure 3.
Sample of the interactive online software provided



2.3. Pedagogical implementation of the intervention

All participating teachers were maths teachers and none of these teachers had any prior engagement with the spatial thinking intervention. Training was provided to teachers before the start of the intervention, as well as continuously during the intervention in the form of professional development (PD) days to ensure that all participating teachers were able to provide an equal level of support to their students. During the PD days, there was a focus on improving the teachers' ability to complete each module, as well as the development of key pedagogical approaches that could be used to implement the intervention. Teachers were provided with a teacher resource booklet, as well as an opportunity for online collaboration throughout the intervention in order to reduce any potential issues in the delivery of the intervention.

3. RESULTS

As this paper mainly focussed on the implementation of the intervention and the challenges surrounding that, not all statistical results will be examined. It is also important to note that this intervention took place over a very short period of time and so the data is merely used to provide indications of future potential. However, an overview of spatial testing performance will be provided to demonstrate some of the preliminary impacts of the intervention.

3.1. Student performance

The control group participants achieved a mean score of 14.62 on the pre-test PSVT:R and a mean score of 14.91 on the post-test. A paired Mann Whitney U test ($W = 883$, $p > 0.05$) indicates that there was no statistically significant difference between pre-test and post-test performance (Fig .4). The experimental group participants achieved a mean score of 15.12 on the pre-test and 16.76 on the post-test, with a Mann Whitney U test ($W = 3266.5$, $p < 0.05$) indicating a statistically significant difference between pre and post-test performance (Fig .4). This suggests that engaging with the intervention had a positive impact on student spatial skills.

When looking at the experimental group alone, male participants achieved a mean score of 17.16 while female participants achieved a mean score of 13.64 on the pre-test. A Mann Whitney U test ($W = 6573.5$, $p < 0.05$) indicates a statistically significant difference among the groups on pre-test performance (Fig .5). On the post-test PSVT:R male participants achieved a mean score of 18.1 while female participants achieved a mean score of 15.9. A Mann Whitney U test ($W = 5982.5$, $p < 0.05$) indicated that there was still a statistically significant difference between the groups after the intervention (Fig .5), however it is interesting to note that the female participants improved more on average in comparison to the male participants, with the intervention being 3 times more effective for females.

3.2. Teacher performance

Teachers engaged in delivering the intervention achieved a mean score of 14 on the pre-test PSVT:R and a mean score of 15.56 on the post-test. A Mann Whitney U test ($W = 2$, $p < 0.05$) indicated a statistically significant difference between pre- and post-test performance (Fig .4). This suggests that taking part in the PD days and delivering the intervention had a positive impact on teachers' own spatial ability as measured by the PSVT:R test.

Figure 4.
Pre-test vs post-test performance among groups on the PSVT:R

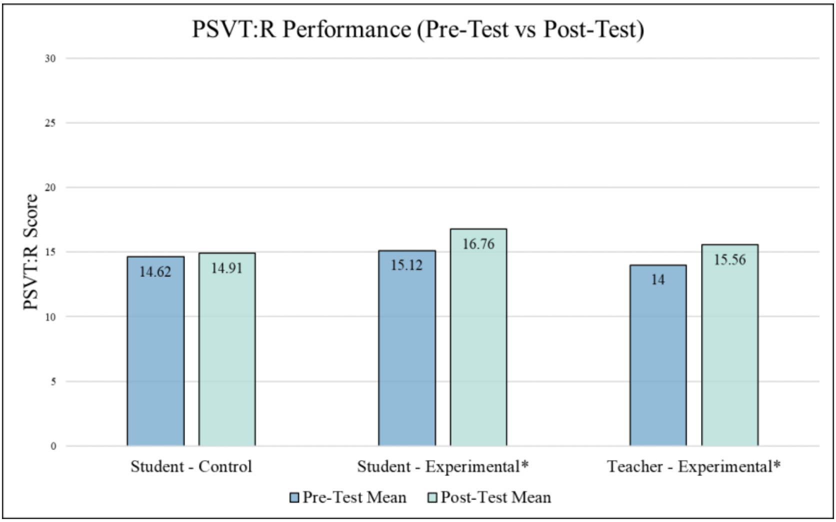
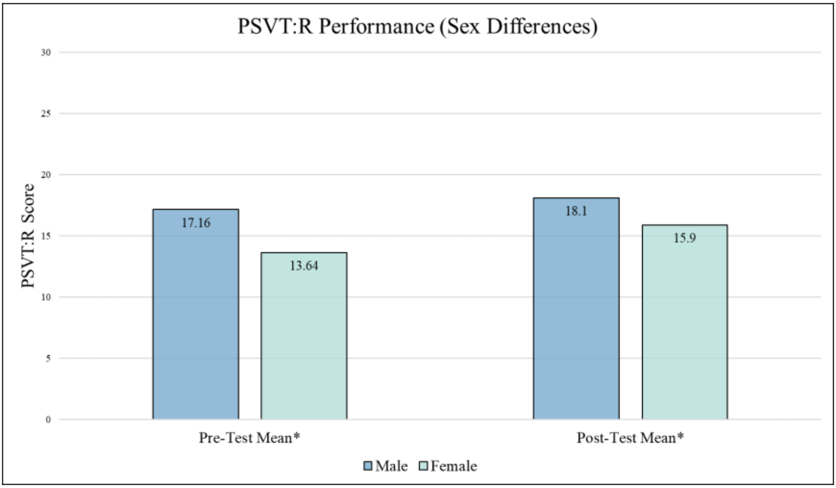


Figure 5.
PSVT:R performance among sexes in pre-test and post-test



4. DISCUSSION

Statistical results described above suggest that engagement in the intervention had a positive impact on student spatial ability as measured by the PSVT:R. This provides a positive indication of future success of the intervention, with the added observational data to support its optimisation. After completing the intervention there was still a statistically significant difference between male and female participants, with male participants outperforming females. What was interesting however was that female participants improved more than male participants, this is something of interest to the researchers and will be investigated in future work.

Through this piloting process, both the researchers and the teachers were met with challenges involving its implementation. This observational and reflective information gathered through discussions with participating partners, teacher, and observation of both PD and practice is more of a focus within this paper and is described below.

4.1. Buy-in/motivation

Attitudes towards the intervention or 'buy-in' was something of noted importance to the researchers, with various aspects to be considered. From the teacher perspective, their own attitudes towards the intervention were quite positive with the majority of the teachers enthusiastic about the prospect of taking this initiative into their own classrooms. This was evident through discussion and engagement levels, which fed directly into the success of the PD days. This enthusiasm however was met with understandable uncertainty, around student engagement and time management of the intervention. Most prominent concerns of teachers were the engagement of their students with such abstract content, as well as the short time span of the intervention and whether this was achievable. However, after the intervention had begun, the feedback from teachers surrounding student engagement was quite positive, with most teachers commenting that their students showed strong levels of enjoyment and engagement throughout their lessons, noting that the content being novel to students supported engagement and interest. One concern raised by teachers was the lack of awareness among students as to the reasoning behind the intervention, with this causing some students to become disengaged as the intervention went on. A possible solution to this problem would be to create a set of resources for teachers to use which highlight the importance of spatial skills, where they are used, and how we can improve them, to ensure student understanding and awareness. Another concern reflected the TY context itself where students participate in regular individualized activities and field trips which effect the class participation and ability to follow the content in the designed order and time span.

4.2. Abstract and repetitive content

As mentioned above the students appeared to find interest in the novel content they were engaging with, however it was discussed that this interest/motivation decreased when they were faced with more abstract content, as they found it difficult to link back to the subject. This decrease in motivation could also occur due to the relatively repetitive structure of the course. If teachers decided to only follow the recommended flow of the lesson without altering its order or adding additional activities to increase its differentiation, students tended to not enjoy its structure as much by the end of it. Through discussions with the PDST, the universities involved, as well as the teachers, it was noted that future iterations of the intervention should place more emphasis on implicit teaching of the content through subject specific resources in order to create a strong link between intervention and subject tasks and ensure that more diverse extension activities and differentiation materials are provided in addition to the established course.

4.3. Order of progression

Another concern raised by teachers was the order in which the modules were presented. These were presented in an order thought to be suitable by the researchers but from engaging directly with students, teachers suggested a more suitable order of progression. Future implementations of the intervention should utilise teacher input when considering the order in which modules should be conducted.

4.4. Teacher professional development

While the PD days were well received by participating teachers, there were suggestions that these should include more discussion and exploration of pedagogical approaches as opposed to focussing on the content. It should be noted that there was a mixture of both included, but the pedagogical discussions were of a descriptive nature. From discussion with the participating teachers, the PDST, and the universities involved, it is recommended that the next iteration of the PD days focus more heavily on explicitly showing and discussing pedagogies to support the intervention, through example lessons and demonstrations, while also allowing time to explore the content itself.

4.5. Establishing a teacher professional community

This study tried to establish a professional teacher community by encouraging teachers to interact with each other throughout the professional development days and ensure there are two teachers from the same school, working with the course at the same time, so they can help each other out when teaching. Also, the spatial website, designed for this study incorporating all spatial materials had a 'teacher collaboration space' to encourage more discussion. Unfortunately, this was not used. Possible other ways to elevate the establishment of the community could include in-person meetings. However, these are difficult to plan and execute.

4.6. Teacher and student testing

From the researcher's perspective, data collection within the study was something that required some improvement. All student testing was completed on a pen-and-paper basis. This made sure that all students had access to the testing (no need for internet access, devices, etc.) but it made data collection both slow and, in some instances, impossible. The collection of paper-based tests in itself is slow, which was expected by the researchers, but the interpretation of handwriting was a more prominent issue than expected with some tests being impossible to read. This is also true for the teacher logs collected. While paper-based tests are useful to ensure access, a hybrid approach may reduce the issues mentioned above. This hybrid approach would allow all students to access the testing, but also streamline the collection through digital measures, however it is unclear how this hybrid approach may impact the validity and reliability of the testing. Another problem with testing can be engagement, especially if there is a lot of it. Engagement with the teacher logs was notably low, which may have been caused by the heavy workload already adopted by teachers when undertaking the intervention. It is recommended that future research is mindful of this, and only necessary data collection is undertaken.

4.7. Student views

When reviewing the intervention, and determining its success as a pilot study, researchers felt that it lacked the student's viewpoint. Yes, student views were discussed as observed by teachers, but direct student opinions would be useful in the improvement of the intervention. Future implementations of the programme should facilitate the collection of student attitudes towards the intervention.

5. CONCLUSION

Through this paper we can see that the short PDP was effective in preparing mathematics teachers to deliver the novel spatial course, and that the implementation of the intervention lead to the significant improvement in spatial ability. It can also be seen that the results indicate a reduction of the gender gap in spatial ability. This indicates a level of success which supports the motivation for future implementations of the program. The context of TY was suitable for the implemented intervention, and it could be seen that the students engaged positively with the intervention. There are also some aspects which can hinder its efficacy, for example the second half of the academic year becomes busier with field trips, which lowers the attendance rate and in turn engagement levels. The points above provide a snapshot of the critical points identified upon reflection of the intervention. This list is not exhaustive but should be considered when implementing similar interventions within a secondary level setting. Overall, the intervention needs to be flexible and reflective of the context in which it is implemented. These suggestions may offer some support when designing such an intervention.

6. REFERENCES

Bowe, B., Seery, N., & Buckley, J. (2016). Spatial skills in education: A national study. IMC33-33rd International Manufacturing Conference.

Bransford, J.D., Brown, A.L. & Cocking, R.R., eds. (2000). How People Learn: Brain, Mind, Experience, and School: Expanded Edition (p. 9853). National Academies Press. https://doi.org/10.17226/9853

Buckley, J., Seery, N., & Canty, D. (2018). A Heuristic Framework of Spatial Ability: A Review and Synthesis of Spatial Factor Literature to Support its Translation into STEM Education. Educational Psychology Review, 30(3), 947–972. https://doi.org/10.1007/s10648-018-9432-z

Buckley, J., Seery, N., Canty, D., & Gumaelius, L. (2018). Visualization, inductive reasoning, and memory span as components of fluid intelligence: Implications for technology education. International Journal of Educational Research, 90, 64–77. https://doi.org/10.1016/j.ijer.2018.05.007

Darling-Hammond, L., Hyler, M., & Gardner, M. (2017). Effective Teacher Professional Development. Learning Policy Institute. https://doi.org/10.54300/122.311

Duffy, G. (2017). Spatial thinking in the engineering curriculum: An investigation of the relationship between problem solving and spatial skills among engineering students. Technological University Dublin.

Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). Manual for kit of factor-referenced cognitive tests, 1976. Educational testing service.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What Makes Professional Development Effective? Results From a National Sample of Teachers. American Educational Research Journal, 38(4), 915–945. https://doi.org/10.3102/00028312038004915

Guay, R. (1976). Purdue spatial vizualization test. Educational testing service.

Kautz, T., Heckman, J. J., Diris, R., ter Weel, B., & Borghans, L. (2014). Fostering and Measuring Skills: Improving Cognitive and Non-Cognitive Skills to Promote Lifetime Success (No. 20749; NBER WORKING PAPER SERIES).

NCCA, N. C. for C. and A. (n.d.). Transition Year Programmes – Guidelines for Schools. https://ncca.ie/media/2512/ty_transition_year_school_guidelines.pdf

NCCA, N. C. for C. and A. (2019). Junior Cycle Graphics Specification. Department of Education and Skills. https://curriculumonline.ie/getmedia/ca152005-ae74-4360-914e-67da18f67474/Graphics.pdf

Newcombe, N. (2010). Picture this: Increasing math and science learning by improving spatial thinking. American Educator, 34(2), 29.

Newcombe, N. (2017). Harnessing Spatial Thinking to Support STEM Learning. OECD Education Working Papers, No. 161. OECD Publishing.

Schneider, W. J., & McGrew, K. S. (2012). The Cattell-Horn-Carroll model of intelligence.

Sorby, S., & Baartmans, B. J. (2000). The development and assessment of a course for enhancing the 3-d spatial visualization skills of first year engineering students. Journal of Engineering Education, 89(3), 301–307. https://doi.org/10.1002/j.2168-9830.2000.tb00529.x

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. Psychological Bulletin, 139(2), 352–402. https://doi.org/10.1037/a0028446

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. Journal of Educational Psychology, 101(4), 817–835. https://doi.org/10.1037/a0016127