Exploring Spatial Skills and Computing in Primary and Secondary Education

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ABSTRACT

This workshop aims to break down the connection between spatial skills and STEM - particularly computing - and highlight existing research of value, presenting an argument for spatial skills instruction in schools. We will discuss known challenges and obstacles to delivery, and aim to collect further challenges from participants. We will then consider effective means of developing spatial skills, and measuring potential outcomes (particularly in computing science), that could be generally applied across multiple schools concurrently with limited training and resource costs. The resulting pack should be a theoretical solution which could potentially be practically implemented across multiple schools.

CCS CONCEPTS

• **Social and professional topics → K-12 education**.

KEYWORDS

spatial skills, primary school, secondary school, intervention, workshop

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1 INTRODUCTION

Spatial skills research has been associated with success in STEM domains for decades. In most cases the connection is correlational [3, 9, 11, 12, 14, 20, 26–28, 33], though causality has been demonstrated in multiple disciplines [18, 22, 32]. In computer science in particular two studies have attempted to demonstrate causality, with one study having some threats to validity [32] and another not reaching significance, possibly due to the small sample size and the measure of computing being used [7]. Regardless, along with the wealth of correlational evidence now existing in computing research to date [12, 13, 19], these results are promising, and indicate that training spatial skills may well be beneficial to computing science outcomes.

2 BACKGROUND

2.1 Spatial Skills and STEM

The first published connection between spatial skills and STEM success was by Super and Bachrach [26] in 1957, who identified that spatial ability was notably high among professionals in scientific domains. Another major discovery was made by Wai et al. [33] as a result of reviewing Project Talent data. Project Talent was a major undertaking in the USA in the 1970's in which around 400,000 high school students were assigned a battery of tests covering various skills and knowledge, one part of which was spatial skills. Based on follow up data collected over the next eleven years, Wai et al. [33] discovered that of the participants going on to achieve a PhD in a STEM domain, a high proportion were in the top spatial skills scoring bracket for the test taken in high school.

Around this work, publications have been produced over the years connecting spatial skills and various specific STEM domains, including but not necessarily limited to physics [14, 18], chemistry [20], engineering [22, 23, 25], maths [6, 17, 28, 34] and computer science [7, 12, 13, 19, 32]. The connection covers a range of outcomes, with spatial ability having an impact on: grades and GPAs, retention on courses and programmes, ability to perform particular domain tasks, and confidence levels, to name a few. There is little doubt that spatial skills have an effect on a broad collection of abilities and practices across STEM and should not be ignored.

2.2 Spatial Skills and School-level Education

The examination of the role of spatial skills in primary and high school has begun to be explored in earnest in recent years. It is known that spatial skills can be developed in school-age children by the following means (supplied by Davis et al. [8]):

- Unstructured construction play [5]
- Directed puzzle play [4]
- Drawing games [30]
- Paper folding [1, 29]
- *Training on a mental transformation task [6]
- *Directed construction play [10]
- *In-class spatial reasoning intervention [15]

Items marked with a * indicate that the intervention was designed (successfully, in each case) to improve mathematics outcomes for the participating pupils. These examples of effective spatial skills development in schools present an encouraging outlook on the nature of potential future training: they indicate that weaving spatial skills training into curricula may not require expert training or extraneous resources, simply a thought towards directing play and naturally occurring learning towards beneficial exercises.

While spatial skills development or instruction is starting to take root in mathematics, with increasing interest from more and more

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parties each year, computing science lacks the same momentum. We understand that well established spatial skills correlate with success in many STEM domains, including computing, therefore should be considering how to incorporate the development of these abilities as computing science is introduced to students.

3 CHALLENGES

While the background research in this area is indeed promising, the following challenges can be identified when considering spatial skills development in schools:

Measuring spatial skills. Spatial skills themselves are not easy to understand: similarly defined concepts of spatial skills are often conflated, disregarding subtle differences; the way spatial skills are structured as a collection of skills differs, as can be seen when comparing Uttal's grid model [31] with Carroll's hierarchical structure [2]; many different tests exist for the multitude of different spatial skills factors, so selecting the correct one(s) can be difficult. Not only does this pose serious experimental challenges and threats to validity if the concepts are misunderstood or poorly explained, it can cause spatial skills research to appear as an impenetrable mass with no access route for the uninitiated.

Determining outcomes. In order to determine if spatial skills development is effective, certain outcomes must be reviewed. In university level studies these tend to be grades, which are uniform, naturally occurring in most domains and measured with reasonable frequency. While schools do of course have exams, they tend to be fewer and further between, so may be a difficult tool to use to measure the impact of spatial skills instruction. Moreover, other outcomes may also be highly relevant to the effectiveness of the instruction, such as confidence level or engagement. These are not determined by exams, so additional tools and resources must be found and applied.

Perceived requirement of expert knowledge. Touched upon above, spatial skills are complex and often discussed in inaccessible, obfuscating language. One may think, then, that spatial skills development is just as complicated, but it does not need to be: aside from the examples provided above, which require little-to-no expert knowledge, Sorby has developed a workbook to be used by engineering students to train spatial skills which is fairly self-explanatory [24]. Expert knowledge will not be required in many cases to develop spatial skills, however this needs to be effectively communicated to teachers.

4 WORKSHOP STRUCTURE

The purpose of this workshop is to discuss the challenges above and determine approaches to overcoming them in order to better prepare teachers to begin (at least laying the ground work for) spatial skills instruction and monitoring. Of course, the list of challenges above is far from exhaustive, so any criticism of the listed challenges or further additions are most welcome.

We will consider these challenges as we discuss the potential for interventions to be included in schools. We will consider the most suitable time frame and method of delivery in different contexts, spanning primary and secondary school classrooms. We will also discuss how to affect perceptions: this will include a review of arguments that are likely to be convincing to pupils and school staff and how they should be portrayed for maximum effect, whilst still being clear and transparent about how much we still do not know. Computer science should be considered in particular, since there is arguably less of a spatial element than (eg.) maths or engineering, where visualisation and construction of spatial models is crucial at a surface level and can be clearly observed

The final goal of this workshop is to have decided upon a strategy to develop the spatial skills of pupils across multiple schools which is accessible to pupils and teachers, effective in context and measurable in terms of outcomes. This could be in the form of a proposal for a spatial skills intervention pack, with training and testing resources, guidance for staff, a testing and training timeline, etc. This will combine the practical need for spatial skills interventions in schools with the research rigour required to strengthen our understanding of spatial skills at a school level.

5 POTENTIAL IMPACT

In the absolute worst case scenario, a spatial skills intervention in primary and secondary schools will have little effect on their outcomes beyond improving their spatial ability. In such an event, we will still have developed a useful skill for the participants at a low resource cost (considering that the developed pack should be easy and inexpensive to implement). However, such an outcome is unlikely, given how much research indicates that training spatial skills is of value across many STEM domains.

It has been speculated by Newcombe [16] that spatial skills training in schools may impact on the gender gap in STEM, though she also acknowledges that, based on work by Uttal et al. [31], girls and boys will likely develop spatial skills at the same rate. However, by raising the overall spatial skills of pupils to a certain level, it is likely that these skills will no longer be a barrier to interest and ability.

Confidence levels are also connected with spatial ability, which has been demonstrated in maths: pupils with poorer spatial skills are less confident than those without, and consequently are less likely to continue in the domain even if their scores and grades surpass their more confident peers [21]. Addressing the confidence rift felt by some students will likely improve entry to STEM domains by people who have the ability and grades but lack the confidence.

Spatial skills are easy to train. Uttal et al. [31] reviewed many different training techniques and Davis et al. [8] highlight methods used in schools, some of which don't require additional resources or teacher training at all. As our understanding of spatial skills develops and the list of benefits grows, supplemented by the knowledge that the training is easy to apply, we should be applying more pressure to include interventions in the curricula.

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