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Visuospatial Training Improves Elementary Students' Mathematics Performance

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Background. Although spatial ability and mathematics performance are highly correlated, there is scant research on the extent to which spatial ability training can improve mathematics performance.

Aims. The present study evaluated the efficacy of a visuospatial intervention program within classrooms to determine the effect on students' (a) spatial reasoning and (b) mathematics performance as a result of the intervention.

Sample. The study involved grade six students (ages 10-12) in 8 classes. There were 5 intervention classes ($n = 120$) and three non-intervention control classes ($n = 66$).

Methods. A specifically designed 10-week spatial reasoning program was developed collaboratively with the participating teachers; with the intervention replacing the standard mathematics curriculum. The five classroom teachers in the intervention program presented 20 hours of activities aimed at enhancing students' spatial visualization, mental rotation and spatial orientation skills.

Results. The spatial reasoning program led to improvements in both spatial ability and mathematics performance relative to the control group who received standard mathematics instruction.

Conclusions. Our study is the first to show that a classroom-based spatial reasoning intervention improves elementary school students' mathematics performance.

Visuospatial Training Improves Elementary Students' Mathematics Performance

Spatial ability has been established as a critical skill for everyday tasks such as learning, training, and working (David, 2012; Kurtuluş, 2013; Rafi, Samsudin, & Said, 2008). Spatial ability helps us to understand, appreciate and interpret our geometric world (National Council of the Teacher of Mathematics [NCTM], 2000); including navigating our surroundings, positioning furniture in a room, and visualizing a diagram while solving a mathematics problem (Booth & Koedinger, 2011). In fact, it would be difficult to engage on a daily basis without spatial skills since they are necessary to understand the relationships between objects, give and receive directions, and imagine changes in the position and size of shapes (Smith, 1998). General definitions of spatial ability involve the ability to “both understand and solve descriptive geometrical problems, and reading and sketching technical drawings” (Contero, Naya, Company, & Saorin, 2007, p. 470) and “generate, retain, retrieve, and transform well-structured visual images” (Lohman 1994, p. 1000). Despite the variability in definitions (Hegarty & Waller, 2005), it is clear that spatial abilities are an overarching set of skills that allow us to represent, navigate and interpret the world around us.

Components of Spatial Ability

Definitions of spatial constructs are not clearly defined in the research literature. Uttal et al., (2013) provides a topology that considers well regarded definitions from Linn and Petersen (1985) and Carroll (1993). Our working definition is based around Linn and Petersen's (1985) categories of spatial visualization, mental rotation and spatial perception. Linn and Petersen's (1985) define spatial visualization as multistep “manipulations of spatially presented information” (p. 1484), whereas mental rotation is the ability to mentally rotate two or three-dimensional figures and to imagine their positions after they are rotated around an axis. We, however, have used Kozhevnikov, Hegarty, and Mayer's (1999) term of

spatial orientation rather than spatial perceptions—“the ability to imagine how a stimulus array will appear from another perspective” (p. 4).

Malleability and Training of Spatial Ability

There is a growing belief that spatial ability is malleable and can be improved with training (Uttal, Miller, & Newcombe, 2013; Wright, Thompson, Ganis, Newcombe & Kosslyn, 2008) yet there are contradictory findings about the effectiveness of spatial training. Whereas some studies report improvement in spatial skills after the implementation of spatial training courses (Sorby, 2009), others suggest the impact of training effects are not significant (Sims & Mayer, 2002). In a recent meta-analysis of the spatial training literature, Uttal, Meadow and colleagues (2013) found that, in general, spatial skills are moderately malleable and spatial training improves performance on average. Among the wide variety of training approaches three main categories of intervention were shown to improve spatial ability; those that used video games, those that used a semester-long or instructional course, and those that trained participants through practice or computerized lessons.

Studies have been undertaken to separately examine effects of training on development and capacity on components of spatial reasoning. Sanchez (2012) argued that improved visualization influenced how individuals processed spatial information and this cognitive change improved test performance. Similarly, Blüchel, Lehmann, Kellner, and Jansen (2013) showed that targeted spatial skills training could improve children's mental rotation performance. The authors, however, did not investigate the transferability of mental rotation training to other motor or cognitive skills. Other studies have shown that training programs do not universally improve all components of spatial reasoning—a study by David (2012) revealed most significant gains in mental rotation for lower ability students, while in Taylor and Hutton's (2013) investigation, improvement was found in spatial visualization and not mental rotation.

Relationship between Spatial Ability and Mathematics

Numerous studies have highlighted the positive relationships between mathematics performance and spatial ability. Much of this evidence arises from the fact that those who perform better on spatial tasks tend to perform better on tests of mathematical ability (Holmes, Adams, & Hamilton, 2008; Rasmussen & Bisanz, 2005). There is some agreement that mathematics is spatial in nature (Jones, 2002), while others argue that similar areas in the brain are activated when people conduct spatial and number tasks (Hubbard, Piazza, Pinel, & Dehaene, 2005). It has been suggested that in order to perform at a higher level of mathematical achievement, students need to be able to imagine and visualize (Battista, Wheatley, & Talsma, 1982; Fennema & Sherman, 1977), with spatial visualization ability predicting talent in mathematics (Shea, Lubinski, & Benbow, 2001; Wei, Yuan, Chen, & Zhou, 2012).

These relations have been found from the early years of school (Kurdek & Sinclair, 2001) and are still prevalent with college graduates (Wai, Lubinski, & Benbow, 2009). The fact that spatial visualization predicts success in geometric reasoning (Battista, 1990) seems plausible since both require the transformation of 2-D and 3-D objects. Moderate relationships between spatial ability and traditional word problems exist (Hegarty & Kozhevnikov, 1999), even though the mental or physical manipulation of objects is not required. Mix et al. (2016) found that mental rotation best predicted mathematics performance in younger students, while spatial visualization was the best predictor of performance by Grade 6 (especially place value, word problems and algebra concepts). Other studies have revealed strong associations between visuospatial ability and performance on number line tasks (e.g., Simms, Clayton, Cragg, Gilmore & Johnson, 2016), even when expertise is accounted for (Sella, Sader, Lolliot & Kadosh, 2016).

It is noteworthy that school curricula are becoming increasingly spatial and graphic in nature with mathematics, in particular, moving away from predominantly word-based tasks to multiple forms of quantitative information (Lowrie & Diezmann, 2007). As Kosslyn (2006) suggested, spatial demands include graphics information and also the information embedded in the task that relates to the graphics. Most national and international mathematics assessment programs have a high proportion of tasks that contain information graphics that need to be decoded. Lowrie and Diezmann found that correlations between spatial ability and various types of graphics-rich tasks were stronger than the individual correlations between those graphics (e.g., line graphs and pie charts). In terms of school curricula, there have been persistent calls to raise students' proficiency in visual and spatial reasoning across all disciplines and school subjects (National Research Council, 2006). Spatial ability has been identified as one of the general numeracy capabilities in the Australian Curriculum (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2015) and an explicit learning process in the Singaporean curriculum (Ministry of Education [MoE], 2006).

Although there has been considerable research on how to improve spatial ability, few studies have considered the effect spatial training has on STEM learning (Stieff & Uttal, 2015; Uttal, Miller, & Newcombe, 2013). Uttal, Miller and Newcombe argued that "improving spatial thinking can help provide the skills necessary to succeed in STEM fields" (p.372). Cheng and Mix (2014) hypothesized that spatial training can improve mathematics learning. In their study, they tested 58 6- to 8- year old children on a range of number and mathematics skills. The spatial training group received one 40-minute training session consisting of mental rotation practice and then completed three post-tests (mental rotation, spatial relations, and mathematics tests). Results showed improvement on children's calculation skills, especially on missing-term problems. Claiming to be the first to show a

direct effect of spatial training on math performance in early elementary children, this study added support to the belief that spatial ability and mathematical reasoning are connected.

Hawes, Moss, Caswell, and Poliszczuk (2015) extended the spatial training time in Cheng & Mix's study to a more extensive six-week program. They assigned 61 6- to 8- year old children to either computerized mental rotation training or literacy training. All children were pre-tested in identical tests, played games on iPad devices three times a week (4.5 hours in total), and post-tested after the intervention. The tests included the Children's Mental Transformation Task (Levine, Huttenlocher, Taylor, & Langrock, 1999), and the Visual-Spatial Puzzle Task (Hawes, LeFevre, Xu, & Bruce, 2015). The findings revealed significant gains on two measures of 2D mental rotation in children who received mental rotation training. However, contrary to Cheng and Mix's study (2014), the results of this research did not show any improvement in children's calculation skills. In other words, children in both condition showed similar improvements on nonverbal exact arithmetic and missing term problems.

Given the significance of spatial ability for success in STEM fields, in general, and math, in particular, more research is needed to identify particular methods of training that can improve math performance (Bruce & Hawes, 2015; Hawes, Moss, et al., 2015; Uttal, Miller, et al., 2013). A majority of studies on spatial training have been carried out in laboratory settings. There is a need for research that bridges the gap between lab-based research and classroom practice (Hawes, Moss, et al.). For example, the Cheng and Mix (2014) study involved one intervention class only. Moreover, the intervention was not conducted in the student's class, with their own teacher.

The present investigation aims to address these gaps in the research literature through the design of an intervention program that has the following features: (i) implemented in situ in regular class settings; (ii) designed collaboratively with the participating teachers who also

received a professional development booklet in spatial reasoning; (iii) implemented over a relatively extended period of time (10 weeks); (iv) using an ecologically valid output measure that covers mathematics content as defined by the Australian Curriculum; (v) with theoretical foundations that focuses on three dimensions of spatial reasoning, namely mental rotation, spatial orientation and spatial visualization. Previous research has essentially focused on only one dimension of spatial ability, particularly mental rotation.

Spatial Ability and Gender Differences

There have also been a number of studies that highlight differences in the performance of males and females across the spatial constructs, however with inconsistent results. As suggested by two meta-analyses (Linn & Petersen, 1985; Maeda & Yoon, 2013), males usually score higher on spatial ability tests. With respect to intervention programs, successful programs can increase the performance gaps in favour of males (Reilly & Neumann, 2013), especially with studies that focus on the mental rotation construct (Maeda & Yoon, 2013). By contrast, other studies have shown that females and males improve their performance at similar rates through intervention programs (Baenninger & Newcombe, 1989; Terlecki, Newcombe, & Little, 2007). Further studies have shown that females benefit more from spatial training and experience if they are supported with encouraging feedback (Moè, 2009). Moè found that women's performance was influenced by positive instructions about gender and they performed better and reached men's scores in the mental rotation tasks. Since the literature is so varied on this matter, we deemed it necessary to investigate this in the present study.

The Present Study

The present study evaluated the efficacy of a visuospatial intervention program in situ to determine whether students' (a) spatial reasoning and (b) mathematics performance increased as a result of the intervention.

Our first research question examined whether visuospatial reasoning (VSR) intervention led to improved visuospatial reasoning performance when compared with the typical mathematics instruction presented to control groups. On the basis of previous research, we hypothesized that the VSR intervention would lead to increased performance on a Spatial Reasoning Instrument (SRI; Ramful, Lowrie & Logan, 2016) that measured spatial visualization, mental rotation and spatial orientation (Blüchel et al., 2013; Sanchez, 2012). The second research question considered the extent to which the VSR intervention led to improvement in mathematics performance compared with the usual mathematics instruction presented to control groups. The VSR intervention replaced the geometry and measurement components of the mathematics curriculum. Importantly, the mathematics test (MathT) covered content from all topics drawn from the mathematics curriculum. In fact, 50% of items were based on concepts not taught in the VSR intervention. Given the control group were receiving curriculum math instruction throughout the course of the intervention, we expected both groups to improve on math scores; however we predicted their scores would be comparable.

Method

Participants

Participants were drawn from six elementary schools in Canberra, Australia. The schools covered a broad socio-economic demographic; with ICSEA¹ scores ranging from 996 to 1194. Eight teachers volunteered to participate, with their classrooms randomly assigned to either (1) an intervention group or (2) a control condition. A total of 186 students were enrolled in the eight participating classrooms.

The intervention group included 120 students (mean number of students per classroom = 24, *S.D.* = 6.5; mean age in years = 11.20, *S.D.* = .62); the 66 non-instruction students (mean number of students per classroom = 22, *S.D.* = 1; mean age in years = 11.36, *S.D.* = .62). There were no significant differences between mean class sizes $F(1, 7) = 0.25, p = .63$, or mean age $F(1, 172) = .023, p = .88$ across the two conditions.

There was a range of experienced and early-career teachers across the two conditions. For the intervention group, classroom experience ranged from 3 years to 19 years ($M = 10.4, S.D = 7.5$). For the control condition, classroom experience ranged from 6 to 23 years ($M = 13, S.D = 8.8$). There was no significant difference between the years of teaching experience in the two groups, $t(6) = 2.60, p = .67$.

Materials

Two instruments were used to measure students' performance over the course of the study.

Spatial Reasoning Instrument. The Spatial Reasoning Instrument (SRI; Ramful, Lowrie & Logan, in press) was based on three constructs (mental rotation, spatial orientation and

¹ In Australia, the Index of Community Socio-Educational Advantage (ICSEA) is used to provide meaningful comparisons across schools. A score (Mean = 1000, *S.D* = 100) is produced for each school, based on Australian Bureau of Statistics (ABS) data, school location, and the proportion of Aboriginal students enrolled in the school. A value on the index corresponds to the average level of educational advantage of the school's student population relative to those of other schools.

spatial visualization) and aligned to the type of spatial manoeuvres that elementary school students tend to encounter in the school curriculum. The 45-item multiple-choice SRI (reported internal reliability was .849; Ramful, Lowrie & Logan, 2016) comprised fifteen items from each of the three constructs (see Figures 1a, 1b, and 1c for examples of items from the spatial visualization, mental rotation and spatial orientation constructs respectively). The constructs have strong correlations with those commonly used in the cognitive psychology literature, namely: Cube Comparison Test ($r = .44$), Paper Folding Test ($r = .60$; Ekstrom et al., 1976); and Perspective Taking or Spatial Orientation Test ($r = .62$; Hegarty & Waller, 2004), however the measure is specifically designed for an elementary school population. Items in the SRI are dichotomously scored, producing a maximum score of 45. The test-retest reliability of the SRI was .81.

INSERT FIGURE 1 ABOUT HERE

Mathematics Test (MathT). We assessed students' mathematics performance using the MathT test, which we developed using released items from Australia's National Assessment Program (NAPLAN). Six of the items were associated with geometry-measurement concepts and six items covered number concepts. The MathT reflects the proportion of geometry and non-geometry tasks in the Australian NAPLAN test. Previous NAPLAN tests were examined and found to contain 50% geometry items in 2013 and 45% geometry items in 2015. Over the past five years the average geometry component of the year 5 NAPLAN test was 55%, the breakdown of item content in the present study was chosen to reflect the proportions present in standard national assessment. To this point, the MathT represented the mathematics content, task representation and arithmetic difficulty of the national mathematics assessment. The 12 multiple-choice and short-answer questions were dichotomously scored. Data were analyzed on the total scores for the MathT, rather than by mathematics content strand, since

we sought a measure for mathematics knowledge (as defined in the national curriculum). The items required the application of mathematics knowledge, rather than routine calculations or drill-and-practice procedures. The test-retest reliability of the MathT was .88. Figure 2 presents an example of a geometry-measurement item (see Figure 2a) and a number item (see Figure 2b).

INSERT FIGURE 2 ABOUT HERE

Structure of the Program

The intervention group teachers delivered the VSR program for two hours per week (in 60 minute blocks) over a ten week period during school hours. The control group instruction during the same period was the geometry and measurement content prescribed by the Australian curriculum.

Intervention program development. The development program for the intervention group was run by the research team over five days of workshops for teachers (totalling 40 hours). The classroom teachers were introduced to the theoretical underpinnings of the project, participated in activities used to describe the three spatial constructs, and helped develop activities for the VSR program implementation. Twenty detailed lessons were produced by the teachers—six lessons for each of the spatial constructs and two lessons that integrated the constructs. The teachers were encouraged to customize the respective lessons to accommodate their personal pedagogical strengths, classroom culture, and student needs whilst ensuring they delivered all content and learning activities described in the twenty lessons. The intervention teachers were provided with support materials (such as handouts) generated during the development to support their classroom teachings.

Content of the visuospatial reasoning (VSR) intervention program. Over the course of the intervention, three weeks (and a total of six hours) were devoted to each of the three

spatial constructs, namely: spatial visualization; mental rotation; and spatial orientation. The final week of the program (two hours) integrated the three constructs via open-ended problem-solving tasks and activities (see Table 1). Each of the spatial constructs was introduced in a manner that encouraged students to develop spatial understandings with the support of manipulatives and concrete materials. As the students became more familiar with these spatial understandings, they were encouraged to become less reliant on the materials and evoke visual representations (in their mind's eye) to solve tasks. The classroom teachers presented the VSR program in a self-contained manner—that is, the teaching of the lessons took place only within the allocated time of the program. The teachers were encouraged not to have additional interaction or engagement with the students on the content of the program.

Each of the three-week blocks provided students with learning experiences that evoked spatial reasoning. The classroom teachers were encouraged to verbalize their thinking, and that of their students, through modelling and scaffolding, as much as possible. They were also encouraged to provide explicit emphasis regarding spatial arrangements in the classroom and the school environment. For example, increased use of Euclidian directional statements and landmark orientation. Table 1 provides a summary of the learning activities presented in the instructional program.

INSERT TABLE 1 ABOUT HERE

Procedure

The tests, administered in two sessions on the same day, comprised the Spatial Reasoning Instrument (SRI) and Mathematics test (MathT). Students completed each test within 50 minutes. The pre-tests were administered to all students within two weeks prior to the implementation of the VSR program. Post-tests were administered within two weeks of the completion of the ten week program. The pre- and post-tests were administered by the research team in the respective classrooms.

Consistency within the VSR program. Program implementation was periodically monitored throughout the VSR program. Two research team members observed three lessons in each classroom—ensuring one lesson from each of the three constructs was monitored. For each lesson, the research team evaluated the teachers according to their adherence to six criteria addressing essential instructional components of the lesson. These components were: 1) lesson objectives; 2) presentation of learning activities; 3) use of concrete materials; 4) focus on key construct; 5) reinforcement of the spatial construct and; 6) promotion of student reasoning. In addition, teachers were asked to maintain an evaluation journal to record reflections and observations regarding lesson implementation and student engagement. Student work samples were collected to verify program implementation. An ANOVA was conducted to determine whether program implementation was consistent across the five intervention classes. There was no statistical difference between the observed lesson components across the five classes $F(4, 14) = 0.72, p = .59$; indicating that important elements of the lessons were introduced in a relatively consistent manner.

The control group mathematics learning activities were drawn from the respective teachers' curriculum program, in a business-as-usual manner. The content covered by the teachers included concepts associated with geometry and measurement, number and algebra, and statistics and probability in accordance with the content descriptors within the curriculum. Since the MathT test was drawn from the national assessment program, the mathematics content delivered to the students was likely to cover topics from the MathT.

Results

The results of the study are presented in two sections. The first section examined the extent to which the intervention and control groups differed before the implementation of the 10-week VSR program. This section also presents correlational data that describes relationships between the variables. The second section presents the effect of the VSR program. Data that examined the effectiveness of the VSR program were analyzed using Analysis of Covariance (ANCOVA) on the post-test scores with pre-test scores as a covariate to control for any possible systematic bias between the two groups (Field, 2009; Maxwell & Delaney, 2004).

Consistency Within and Across the Intervention Design

There was no difference between the mean scores of the intervention and control groups on the SRI pre-test $F(1, 185) = 0.72, p = .39$ or MathT pre-test $F(1, 185) = 2.95, p = .09$. There were strong correlations between the pre-test and post-test measures on the SRI in the intervention ($r = .79, p < .001$) and control ($r = .87, p < .001$) groups. Correlations were also strong between pre-test and post-test measures on MathT scores across the intervention ($r = .77$) and control ($r = .81$) groups. Correlations between SRI post-test and MathT post-test were strong for both the intervention ($r = .79$) and control ($r = .74$) groups.

Effectiveness of the Visuospatial Reasoning Program

Means and standard deviations for the measures by treatment are presented in Table 2.

INSERT TABLE 2 ABOUT HERE

Two-way ANCOVAs were conducted, using pre-test scores as the covariate, to test whether the mean scores on the Spatial Reasoning Instrument (SRI) and mathematics achievement test (MathT) differed between groups (intervention group vs. control) and gender (male vs. female). In addition to p values, effect sizes are reported.

With respect to the spatial reasoning performance, there were statistically significant differences in the mean scores of the two groups in favour of the intervention group $F(1, 185) = 12.36, p < .001, d = .54$. There were no performance differences by gender $F(1, 185) = 0.13, p = .72$. We then conducted three separate ANCOVAs to determine the extent to which performance by group differed across each of the three spatial constructs (means and standard deviations presented in Table 3). There were statistically significant differences on both the spatial visualization $F(1, 185) = 18.03, p < .001, d = .65$ and mental rotation $F(1, 185) = 4.9, p = .01, d = .43$ constructs, in favour of the intervention group. By contrast, there was no difference between the mean scores of the two groups on the spatial orientation items $F(1, 185) = 0.99, p = .32$.

INSERT TABLE 3 ABOUT HERE

In terms of mathematics performance, there were statistically significant differences in the mean scores of the two groups in favour of the intervention group $F(1, 185) = 7.18, p = .02, d = .40^2$. There were no performance differences by gender $F(1, 185) = 0.01, p = .97$. There was a significant correlation between the observed improvement in mathematics and spatial reasoning (as measured by the change in scores between the pre- and post-tests), $r(120) = .21, p = .021$. Figure 3 illustrates the pre- and post-test scores on the MathT and the subscales of the SRI.

INSERT FIGURE 3 ABOUT HERE

² We performed a post hoc analysis to separate the maths test into number based and geometry questions. There were six items in each category. ANCOVAs controlling for pre-test scores revealed a significant improvement for the treatment group in geometry problems compared with the controls, $F(1, 162) = 9.05, p = .003, d = .34$. For the number questions there were no significant differences between the groups, $F(1, 162) = .01, p = .92$. Despite the absence of number instruction for the ten weeks of the intervention, the intervention group were equivalent to the control group in number assessment.

Discussion

This study, which evaluated an intervention that taught explicit spatial constructs to elementary-aged students, was designed to determine the potential of improved spatial ability on mathematics performance. The first objective of this study was to measure the extent to which training improves visuospatial reasoning. We evaluated the effectiveness of an intervention program that taught explicit spatial reasoning constructs and found that those students who participated in the 10-week Visuospatial Reasoning Program had substantially higher spatial reasoning scores than the students in the control group.

We then analyzed performance differences by the three spatial constructs. The VSR program was especially effective at improving students' spatial visualization and mental rotation scores. However, there was no statistically significant improvement on the intervention groups' spatial orientation scores, when compared to the control group scores. Pre-test scores for both intervention and control groups were much higher for orientation items than for the other two constructs (see Table 3), highlighting strong foundational understandings of the construct. It may be the case that students of this age require different aspects of orientation training to establish the next level of construct proficiency and sophistication. Most of the activities that promoted spatial orientation in our program were based on the manipulation of concrete materials to interpret maps and make decisions about perspective. It might be necessary to challenge students to solve such tasks with less reliance on manipulatives, consequently encouraging greater use of imagery. Three especially important components of spatial orientation involve object perspective, map perspective and sense of direction (Kozhevnikov & Hegarty, 2001). Activities that develop these skills may need to progress beyond concrete representations much faster than we anticipated, in order for students of this age to increase their spatial orientation ability.

The second objective of this study was to measure the extent to which training improves mathematics performance. Although an earlier study (Cheng & Mix, 2014) provided initial evidence of such performance increases, the present findings are more robust. Our study involved a much larger sample size, was implemented by classroom teachers in their own classrooms, and measured mathematics performance in terms of a variety of topics covered within the school curriculum (including number, geometry and measurement). Moreover, we evaluated the effectiveness of a sustained intervention program that replaced a substantial component of the participants' usual mathematics curriculum. As such, the Visuospatial Reasoning Program did not involve additional mathematics pedagogy or content during the 10-week intervention phase. Rather, the VSR program replaced the usual teaching of the mathematics topics in the curriculum. Regardless, the intervention group demonstrated broad improvement across mathematics concepts.

There were no gender differences with respect to gain-score improvements across the intervention program. In contrast to other interventions (Maeda & Yoon, 2013; Reilly & Neumann, 2013), our intervention was equally effective for males and females.

Although the VSR program introduced the three spatial constructs in a structured manner, they were implemented via the participants' respective classroom teacher. The mean SRI scores of all intervention classrooms increased, in a relatively consistent manner. The schools were drawn from diverse populations, with the program taught by classroom teachers of considerably different teaching experience. Such findings highlight the strength of the results.

The magnitude of effect size changes for the intervention group on both spatial ability and mathematics performance were substantially and practically important. In a study that analyzed expected effect size changes for intervention programs in mathematics, Hill, Bloom, Black, and Lipsey (2008) argued that an effect size greater than 0.4 represented one year of

mathematics development, for students in Grades 5-6. These data were based on national norming samples of six standardized mathematics tests, by Grade level. Hill et al (2008) indicated that such benchmarking needed to be framed within context, especially with classroom-based interventions. According to Hill's argument, the gains found in the ten week intervention program in the present study equate to a year's worth of standard development.

In fact, this is the first study to demonstrate that a visuospatial intervention program administered by students' own classroom teachers will improve the students' mathematics performance.

Limitations and Future Research Directions

One limitation of our study was the fact that the classroom teachers in the control group did not receive any professional development (PD) as part of the design. The five days of engagement and PD provided to the teachers in the intervention condition may have increased their pedagogical content knowledge in ways that were supportive of students' learning needs beyond the intervention. We were mindful of this, and consciously limited the PD to the development of the VSR program, which provided a structure comparable to that of the national curriculum used by the control group. This limitation was offset by the fact that an aim of the study was to contrast the VSR program with classroom practices and pedagogy that would be considered typical. In addition, we appreciate that the VSR participants may have been additionally motivated by the fact they were engaging with stimulating activities from the program (Boot, Simons, Stothart, & Stutts, 2013). However, the control participants were unaware of the intervention program in other classrooms.

The difference found between the three spatial constructs in this study is noteworthy. Given the high spatial orientation scores across the board it could be that our measure was not sensitive enough to detect differences at the upper end of the construct. Alternatively, previous research has found that game play can support improvements in spatial orientation

(David 2012; Whitlock, McLaughlin, & Allaire, 2012). Future studies could investigate the influence of children's leisure engagement with online games on their spatial orientation scores.

Finally, it is important that future work on the impact of visuospatial training on mathematics performance include a broader participant base—especially more grades in elementary schools. Since spatial understandings are especially important in the formation of mathematics knowledge in the elementary years (LeFevre et al., 2010), it would be worthwhile to include Grade 3 or 4 (8 and 9 year olds) in future studies. Although many of the skills highlighted in our three constructs would be appropriate for implementation in lower grades, such processes should be situated within learning experiences that contained meaningful experiences and opportunities for applications for students of this age.

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Table 1

Summary of Learning Activities in the Instructional Program

Weeks	Construct	Activities
1-3	Mental Rotation	2D rotation around a point; 3D rotation of objects; Rotational symmetry
4-6	Spatial Orientation	Drawing and navigating maps; Orientation around cardinal points; Reading inverted maps; Perspective taking; Identifying different perspectives such as top, front and side view.
7-9	Spatial Visualization	Paper folding and cutting; Nets of solids; Reflection and symmetry; Hidden blocks and block counting.
10	Integration	Differentiating between reflection and rotation

Table 2

Means and Standard Deviations for Measures by Treatment

Measure	Intervention (n = 120)		Control (n = 66)	
	M	S.D.	M	S.D.
SRI pre-test	24.62	7.04	23.40	7.52
SRI post-test	28.36	7.50	25.03	7.20
MathT pre-test	4.83	2.44	4.14	2.22
MathT post-test	6.09	2.71	4.80	5.56

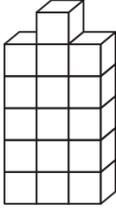
Table 3

Means and Standard Deviations for the Three Spatial Constructs by Treatment

Measure	Intervention (n = 120)				Control (n = 66)			
	Pre		Post		Pre		Post	
	M	S.D.	M	S.D.	M	S.D.	M	S.D.
Spatial Visualization	6.28	2.55	7.52	2.75	5.97	2.80	5.95	2.66
Mental Rotation	7.59	3.14	9.37	3.38	7.41	3.38	8.30	3.06
Spatial Orientation	10.60	2.75	11.30	2.72	10.15	2.72	10.81	2.51

<p>The diagram below shows the net of a cube.</p> <div style="text-align: center;"> </div> <p>When it is folded to form a cube, which edge joins with edge MN?</p> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div style="text-align: center;"> <input type="radio"/> A Edge QR </div> <div style="text-align: center;"> <input type="radio"/> B Edge ST </div> </div> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div style="text-align: center;"> <input type="radio"/> C Edge MP </div> <div style="text-align: center;"> <input type="radio"/> D Edge PQ </div> </div> <p style="margin-top: 10px;">a) Spatial visualization</p>	<p>The figure below shows the picture of a bike.</p> <div style="text-align: center; margin-bottom: 10px;"> </div> <p>Which one of the following shows a rotation of the picture?</p> <div style="display: grid; grid-template-columns: 1fr 1fr; gap: 20px;"> <div style="text-align: center;"> <input type="radio"/> A </div> <div style="text-align: center;"> <input type="radio"/> B </div> <div style="text-align: center;"> <input type="radio"/> C </div> <div style="text-align: center;"> <input type="radio"/> D </div> </div> <p style="margin-top: 10px;">b) Mental Rotation</p>
<p>Kelly was looking at the design below from the position indicated.</p> <div style="text-align: center; margin-bottom: 20px;"> </div> <p>What does the front view of the design look like from Kelly's view?</p> <div style="display: grid; grid-template-columns: 1fr 1fr; gap: 20px;"> <div style="text-align: center;"> <input type="radio"/> A </div> <div style="text-align: center;"> <input type="radio"/> B </div> <div style="text-align: center;"> <input type="radio"/> C </div> <div style="text-align: center;"> <input type="radio"/> D </div> </div> <p style="margin-top: 10px;">c) Spatial Orientation</p>	

Figure 1. Example items from the Spatial Reasoning Instrument.



Carl builds this 3D object using 16 cubes.
He then paints the outside faces of the object including the base.

How many cubes only have 2 sides painted?

a) An example of a geometric item from the Mathematics Test.

Ben has 2 identical pizzas.

He cuts one pizza equally into 4 large slices.

He then cuts the other pizza equally into 8 small slices.

A large slice weighs 32 grams more than a small slice.

What is the mass of **one** whole pizza?

b) An example of a number item from the Mathematics Test.

Figure 2. Example items from the Mathematics Test. Copyright 2010 by the Australian

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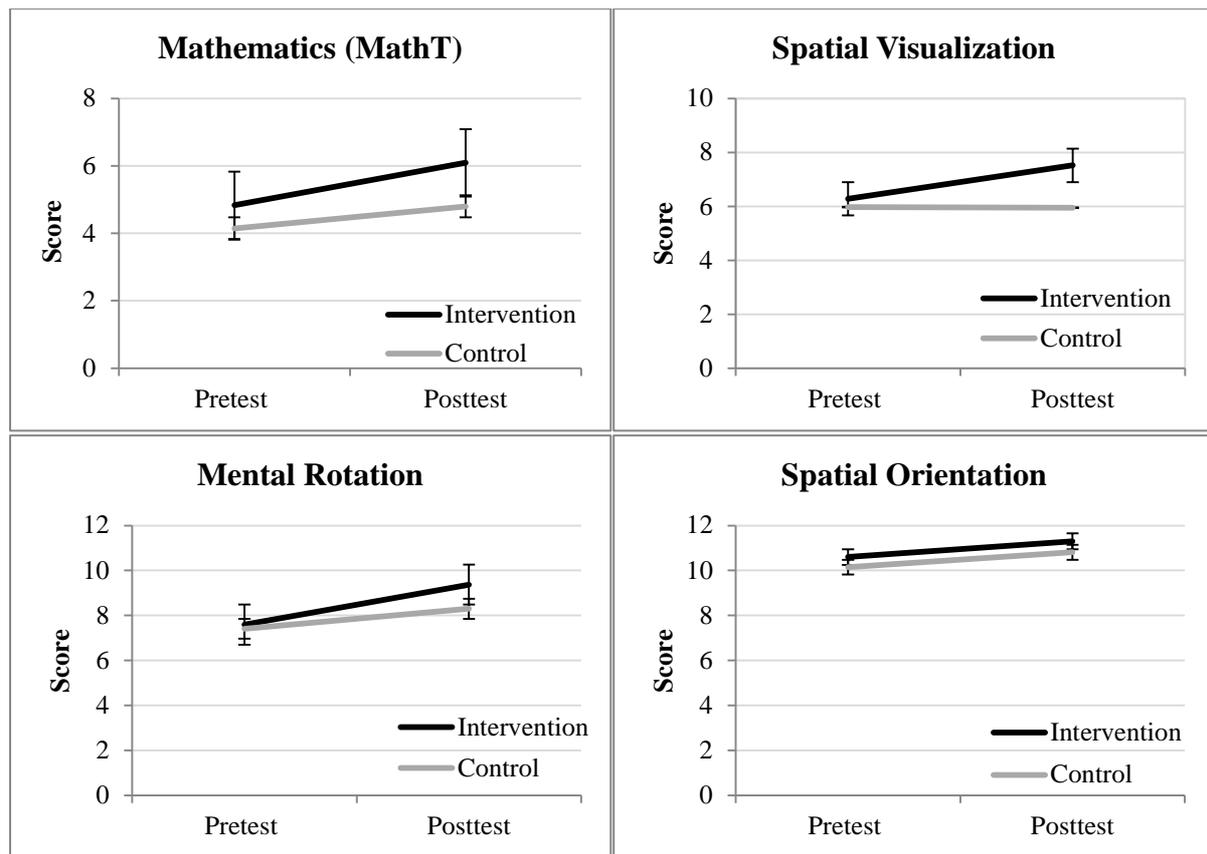


Figure 3. Pre and post-test mean scores (with Standard Error) on the MathT test and SRI subscales.