Spatial Thinking in Practice: A Snapshot of teacher's Spatial Activity Use in the Early Years' Classroom

Katie A. Gilligan-Lee[1,2,3], Alice Bradbury[4], Charlotte Bradley[2], Emily K. Farran[2,3], Jo Van Herwegen[5,6], Dominic Wyse[4], and Laura A. Outhwaite[6]

ABSTRACT— Spatial thinking predicts Science, Technology, Engineering, and Mathematics achievement, yet is often absent from educational *policy*. We provide benchmarks of teachers' usage and perceptions of spatial activities *in practice* in the reception classroom (first year of primary school). In this questionnaire study of educational professionals working in the reception classroom in England (N = 104), we found that spatial and numeracy activities were perceived as significantly less important, and were reportedly completed significantly less often, than literacy or life skills. Despite the lower perceived importance of spatial skills in curriculum guidance in England, rates of reported spatial activity use were encouragingly high and were broadly comparable to those of numeracy. Teachers had moderate anxiety levels for both spatial and mathematics domains. The findings highlight a need to elevate teachers' understanding of the importance of developing children's early spatial and numeracy skills, which may begin with efforts to reduce spatial and mathematics anxiety.

[1]School of Psychology, University College Dublin
[2]School of Psychology, University of Surrey
[3]Centre for Educational Neuroscience, Department of Psychological Sciences, Birkbeck University of London
[4]Helen Hamlyn Centre for Pedagogy, IOE UCL's Faculty of Education and Society
[5]Department for Psychology and Human Development, IOE UCL's Faculty of Education and Society
[6]Centre for Education Policy and Equalising Opportunities, IOE UCL's Faculty of Education and Society

Address correspondence to Katie Gilligan-Lee, School of Psychology, University College Dublin, Ireland; e-mail: katie.gilligan-lee@ucd.ie

Spatial thinking is a recognized gateway to improved Science, Technology, Engineering, and Mathematics (STEM) performance and entry into STEM careers (Wai, Lubinski, & Benbow, 2009). Longitudinal and cross-sectional data show that from early childhood, individuals with higher spatial abilities have better mathematics and science outcomes, compared to those with lower spatial abilities (Bower et al., 2020; Gilligan, Flouri, & Farran, 2017; Hodgkiss, Gilligan, Tolmie, Thomas, & Farran, 2018; Gilligan, Hodgkiss, Thomas & Farran, 2019; Mix et al., 2016). These findings remain even after controlling for IQ and socioeconomic status. A recent meta-analysis summarized these findings showing a positive moderate association between spatial and mathematical skills (r = .36) that was not moderated by gender or age group (Atit et al., 2022). Beyond correlational evidence, meta-analysis findings also show that spatial interventions have a positive effect on mathematics outcomes (Hedges's g = .28) compared to business-as-usual and active controls (Hawes, Gilligan-Lee, & Mix, 2022), suggesting that there is a causal effect of spatial thinking on mathematics. This may be explained by shared neural processing of spatial and mathematics skills, the use of spatial visualization strategies for solving mathematics problems, or the use of spatial symbols (e.g., =, <, >) in mathematics learning (Hawes, Gilligan-Lee, & Mix, in press). However, despite the potential benefits for mathematic outcomes, spatial reasoning lacks formal acknowledgment in mathematics curricula in multiple countries (Gilligan-Lee, Hawes, & Mix, 2022). Indeed, in September 2021 the UK Department of Education removed specific learning objectives (Early Learning Goals) relating to shape, space, and measurement from the Early Years Foundation Stage (EYFS) statutory framework (learning standards for children from birth to 5 years) in England, with an increased emphasis on number skills (Department for Education, 2021). This demonstrates an active de-prioritization of spatial reasoning in the reception classroom (first year of primary school when children are 4–5 years old). Even before this change, spatial reasoning comprised a minimal proportion of all early learning goals (Department for Education, 2017). However, beyond policy, what do educators think about spatial thinking in practice?

Key to children developing proficient spatial skills is that they are awarded opportunities to engage in spatial activities. Educators play a key role in providing spatial opportunities in the classroom, however, as outlined previously in Costa, Outhwaite, and Van Herwegen (2021), there is debate in the early years' literature regarding whether learning in the early years should focus on formal (adult-led) or informal (child-led) activities. Informal learning activities are characterized by discovery-based learning (Baroody & Li, 2009) whereby skills are not explicitly taught. These activities are child-directed and typically self-regulated (Gray, 2015), although they can be supported by teachers (Zosh et al., 2018), for example, jigsaws, crafting, and programming simple toys like Beebots. By comparison, formal learning activities are led by teachers (Ginsburg, Lee, & Boyd, 2008) including explicitly teaching children to gesture, draw maps, and use spatial language. Evidence from other learning domains shows differences in the implementation of informal and formal learning activities, for example, across literacy and numeracy (Costa et al., 2021). However, to date there is no evidence comparing formal and informal spatial activity use in the early years. Although it is often neglected as an explicit part of mathematics instruction, we know that many early years teachers instinctively use spatial reasoning effectively in their classroom (Bates, Williams, Gilligan-Lee, Gripton, & Farran, 2022), and concern was expressed towards the removal of shape, space, and measure as one of the Early Learning Goals (Husain et al., 2019). Despite this, to date, no known studies have explored the role of the teacher in providing spatial opportunities for children in the reception classroom (4–5 years). Here we address this by investigating teacher's usage and perceptions of formal and informal spatial activities in the reception classroom, and how their use of spatial activities compares to other non-spatial domains (literacy and numeracy). Beyond curriculum guidelines and formal learning objectives, the aspiration is that these findings will provide a realistic snapshot of spatial thinking in practice, driven by teacher experiences.

Teachers and other educational professionals are key players in "spatialising" the primary school curriculum, but why do some teachers use spatial activities more regularly and readily than others? This study also investigated how teacher characteristics, including spatial anxiety and the importance placed on spatial skills, associate with reported spatial activity use. It is well-recognized in educational theory that teacher's beliefs and perceptions influence their classroom environments (Fang, 1996), and by extension their students' motivation and achievement (Caprara, Barbaranelli, Steca, & Malone, 2006; Upadyaya & Eccles, 2014). Gagnier, Holochwost, and Fisher (2022) specifically proposed teachers' beliefs and perceptions of spatial thinking directly influence the success of spatial interventions in the classroom. In their study of spatial thinking and science learning, elementary school teachers were asked to rate how important general spatial skills/abilities were for different STEM problems/scenarios. Encouragingly, teachers' scores mirrored those of spatial experts, that is, they rated spatial skills as very important for items that experts also thought were heavily dependent on spatial skills. This shows that teachers can recognize learning scenarios where spatial skills are important. However, outside specific contexts, this study did not ask teachers their general opinions on the importance of spatial skills compared to other academic domains, which may be a better measure of how likely they are to include spatial activities in their teaching. Furthermore, Gagnier et al. (2022) found teachers rated spatial skills as more important for reception-aged children (4–6 years) compared to pre-school (birth-2 years). Thus, reinforcing the need to explore, in-depth, the beliefs of early years teachers regarding spatial skills. The current study measured teachers' perceptions of the importance of spatial thinking relative to other early learning domains of thinking (referred to hereafter as spatial importance). We also explored spatial importance as one possible teacher characteristic that may explain teachers' use of spatial activities in the classroom. In addition to its importance, this study also examined spatial anxiety.

Spatial anxiety is defined as uneasiness towards spatial processing, causing individuals to avoid engaging in any behavioral opportunities that rely on spatial thinking, for example, mental rotation or navigating with a map (Lyons et al., 2018). It is distinct from mathematics anxiety which, as described by Ashcraft and Kirk (Ashcraft & Kirk, 2001 p. 1), is "a feeling of tension, apprehension, or fear that interferes with math performance". Previous research shows teachers' spatial anxiety is negatively correlated with students' (Grade 1 and 2, i.e., 6–8 years) mental rotation task performance at the end of the school year, including when controlling for students' initial spatial skills, working memory, and gender (Gunderson, Ramirez, Beilock, & Levine, 2013). Notably, results persisted after controlling for teachers' mathematics anxiety, thus demonstrating the spatial anxiety measure was not a proxy for general anxiety. Malanchini et al. (2017) also show spatial and mathematics anxiety are distinct from general anxiety.

Mathematics anxiety was measured in this study for two reasons. First, as outlined above including a second measure of subject-specific anxiety provided some evidence that our spatial anxiety measure was not simply a proxy for general anxiety. Second, there exist strong associations between spatial and mathematical thinking (Atit et al., 2022) and previous studies have shown links between mathematics anxiety and spatial ability (Ferguson, Maloney, Fugelsang, & Risko, 2015). Therefore, we wanted to explore whether mathematics anxiety might also influence the use of spatial activities in the classroom.

Research exploring two sub-domains of spatial anxiety (mental manipulation anxiety and visual imagery anxiety) shows primary and secondary school teachers with higher mental manipulation anxiety have lower spatial (mental rotation) performance. However, there was no association between imagery anxiety and spatial skill (Atit & Rocha, 2021). Furthermore, although spatial skill (mental rotation performance) was associated with teacher's efficacy in cultivating students' spatial skills during science instruction, neither sub-domain of spatial anxiety was associated with efficacy (Gagnier et al., 2022). However, the teachers in the sample spanned the entire K-12 system (i.e., 5–18 years), yet opportunities to embed spatial activities into teaching may differ across grades, and results may differ for particular year groups where the mathematics content (curriculum), and by association, the most suitable teaching approaches, may also differ. Therefore, to increase the impact of the current study, we limit our population of interest to educators teaching in the reception (4–5 years) classroom only.

In this study, we compliment *cognitive* findings on spatial and mathematical skills in the classroom (e.g., Hawes et al., 2022), by providing a snapshot of teachers' usage and perceptions of formal and informal spatial activities *in practice*. Our first aim was to compare teachers' frequency of use of formal and informal spatial activities, to similar literacy and numeracy activities. Secondly, we investigated teachers' perceptions of spatial skills, by examining subject-specific differences in how teachers rate the importance of spatial, numeracy, literacy, and daily living skills in the reception classroom (4–5 years). Finally, to further understand why teachers differ in their use of classroom-based spatial activities, we investigated associations between spatial anxiety and spatial importance and reported formal and informal spatial activity use. Identifying factors that contribute to the provision of spatial activity use in the classroom may allow for the design of interventions to support teachers in their spatial activity implementation. In short, here we bridge the gap between theory and classroom application, by providing invaluable insights into teachers' use of spatial thinking *in practice.*

METHODS

Participants

There were 104 participants in the final sample, all of whom identified as working in the reception classroom, of these 91% were classroom teachers, 5% were teaching assistants and 4% were headteachers (average years of teaching experience: $M = 10.5$, $SD = 7.2$, $range = 1–34$) (Figure 1). Note that the inclusion/exclusion of headteachers did not alter the pattern of results reported, and they were therefore retained. The sample was employed across a range of educational settings, including 58% from schools funded by local authorities, 33% from academies (part of a multi-academy trust), 2% from standalone academies, 2% from free schools (schools set up by group/organization that are government funded but not run by local authorities), 5% from private/independent schools and 1% from community schools (state-funded but run by the local education authority). The schools were located across England, including the Northeast (3.8%), Northwest (16.3%), Yorkshire and the Humber (11.5%), West Midlands (5.8%), East Midlands (7.7%), Southwest (15.4%), Southeast (16.3%), East of England (8.7%), and Greater London (14.4%). This demographic information suggests that our sample was representative of teachers across a diverse range of locations and school settings. Participants were recruited via opportunity sampling within the authors' professional networks. They were not reimbursed for their participation.

Procedure

Participants completed an online questionnaire using the online data collection platform Qualtrics. Before taking part, participants read an information sheet about the study and consented using an online consent form. A full copy of the questionnaire can be found in the supplementary materials and on our Open Science Framework (OSF) page

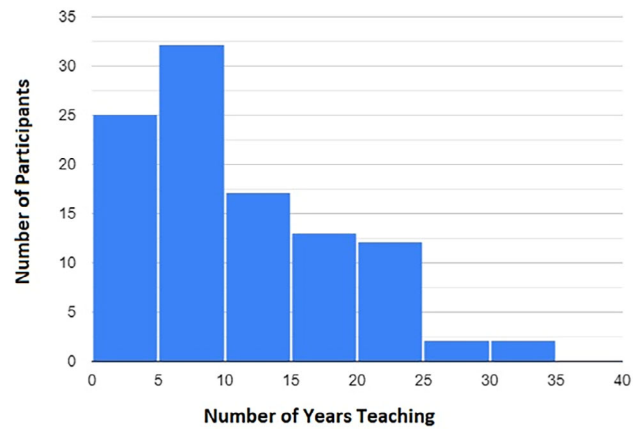

Fig. 1. Graph showing the distribution of teachers with different levels of teaching experience.

Table 1
Sample Items for the Classroom Activity Questionnaire

Skills	*Formal Activities*	*Informal Activities*
Spatial	Sort object by color, size, or shape	Play with programmable toys and computer games that use navigation
Numeracy	Count objects	Weigh, measure and compare quantities (e.g., when cooking)
Literacy	Teach names of alphabet letters	Play rhythm games and sound games

(https://osf.io/bqukr/). Note only sub-components of the questionnaire that are included in the current study are detailed in the measures section below.

Measures

Demographic Information

Teachers answered demographic questions relating to their number of years of teaching experience, their current job role, other teaching responsibilities, the location of their school, and the type of funding that their school received.

Classroom Activity Questionnaire

A Classroom Activity Questionnaire was designed for this study, including items used previously (see Costa et al., 2021). Participants were asked to rate how often they implemented different formal and informal spatial, literacy, and mathematics activities in the classroom. There were 16 items per domain (spatial, numeracy, literacy) with eight formal and eight informal activities each. Examples are shown in Table 1. Participants were asked to respond to each item on a 6-point Likert scale with the options: 'not at all', 'once or twice a term', 'once a week', 'a few times per week', 'everyday', 'several times a day'.

Activity Importance Questionnaire

An importance questionnaire was also designed for use in this study, based on previous research (Costa et al., 2021). These questionnaire items measured the value/importance that teachers placed on the development of different skills in the reception classroom (spatial, literacy, numeracy, and life skills) before children transition to their next academic school year (see Table 2). Participants were asked to respond to five questions for each domain on a 5-point Likert scale with the options: 'not important', 'somewhat important', 'important', 'very important', 'extremely important'.

Mathematics Anxiety

An adapted version of the Abbreviated Maths Anxiety Scale (AMAS) (Hopko, Mahadevan, Bare, & Hunt, 2003) was used

Table 2
Sample Items for the Activity Importance Questionnaire

Domain	*Examples*
Spatial Skills	Use a simple map, respond to and use spatial language
Life Skills	Tie own shoelaces, eat using a fork
Literacy	Write letters of the alphabet, read a few words
Numeracy	Count to 10, know simple sums

to measure mathematics anxiety. This UK-modified version of the measure was taken from Carey, Hill, Devine, and Szűcs (2017). Participants were asked to rate how anxious they would feel in nine different mathematics-related scenarios, for example, being given maths homework with lots of difficult questions that you have to hand in the next day. Participants responded on a 5-point Likert scale with the options, 'low anxiety', 'some anxiety', 'moderate anxiety', 'quite a bit of anxiety', and 'high anxiety'.

Spatial Anxiety

The Mental Manipulation subdomain of the Spatial Anxiety Scale (Lyons et al., 2018) was used to assess spatial anxiety. Due to constraints on the length of our online questionnaire, we did not measure imagery or navigation anxiety sub-domains. As small-scale spatial skills are most closely aligned with the sort of spatial activities that a teacher might complete in the classroom, for example, jigsaws, building blocks, and mental manipulation anxiety has been associated with spatial skill in previous studies (Atit & Rocha, 2021), this sub-domain of spatial anxiety was deemed most appropriate. Participants were asked to rate how much they would be made to feel anxious in eight different scenarios relating to mental manipulation, for example, asked to imagine and mentally rotate a 3-dimensional figure. Participants responded on a 5-point Likert scale with the options, 'not at all', 'a little', 'a fair amount', 'much', and 'very much'.

Data Analysis

For all measures (questionnaires) sum scores were used, where higher scores indicate higher frequency of use, importance ratings, and anxiety. Reliability analysis was run for each of the questionnaire measures. Cronbach's alpha scores indicated acceptable to excellent levels (>.70) for most measures (Table A1). The formal and informal literacy activities were an exception to this as they had poor reliability. The results of these measures should therefore be interpreted in the context of this limitation. Removing items from any scale did not substantially improve reliability, and as many of these measures have been used previously in other studies, all items were retained. Only participants who completed at least one of the questionnaires (excluding the demographic measures) were included. Post-hoc power analysis for the largest analysis (regression with four predictors, α of .05, n = 91, effect size (f^2) = .11) indicated that the achieved power was 80.1%. All data analysis was completed using Jamovi. Bayes factors are reported for all non-significant effects. A BF_{10} between 0.3 and 3 suggests weak support for either hypothesis, a BF_{10} of 3–10 indicates moderate (and > 10 indicates strong) support for the experimental hypothesis, while a BF_{10} of 0.3 to 0.1 indicates moderate (and <0.1 indicates strong) support for the null hypothesis (van Doorn et al., 2021).

RESULTS

Descriptive Statistics

Descriptive statistics are shown in Table 3 and correlations between all dependent variables can be found in Table 4. Although not correlated with the use of spatial activities, years of teaching experience is included as a control variable in subsequent regression models, to explicitly demonstrate that different levels of experience and exposure to a variety of curricula across the years, do not significantly impact the use of spatial activities. Tests of normality demonstrated several of the variables were skewed, and in some cases, Shapiro–Wilk values were less than .05. Given that the sample was larger than 30 participants, the Central Limit Theorem applies here, and parametric analyses were used throughout (Field, 2013).

Teachers' Use of Formal and Informal Spatial Activities in the Classroom

A repeated measures Analysis of Variance (ANOVA) was completed with subject (spatial, numeracy, literacy) and activity type (informal, formal) as independent variables. The dependent variable was the frequency of use. The main effect of the subject was significant, $F(2,194) = 95.53$, $p < .001$, $\eta p^2 = 0.496$. Bonferroni post-hoc tests showed there were significant differences between all subjects ($p < .001$ for all). Collapsed across formal and informal activities, the highest levels of activity were for literacy (69.6 ± 5.8), followed by spatial (63.5 ± 7.0), and numeracy (59.7 ± 6.9). The main effect of activity type, $F(1,97) = 7.37$, $p = .008$, $\eta p^2 = 0.071$ (informal > formal) is best explained within the context of the significant interaction between subject and activity type, $F(2,194) = 89.02$, $p < .001$, $\eta p^2 = 0.479$ (Greenhouse Geisser) (Figure 2). This interaction was explored with two one-way ANOVAs. For formal activities, there was a significant effect of subject, $F(2,194) = 54.3$, $p < .001$, $\eta p^2 = 0.359$. Post-hoc comparisons found that teachers used formal literacy activities most often, followed by numeracy and then spatial activities ($p < .001$ for all). For informal activities, there was also a significant effect of subject, $F(2,194) = 153.0$, $p < .001$, $\eta p^2 = 0.612$. However, the pattern of performance differed, with teachers completing informal literacy and spatial activities with a similar frequency ($p = .648$), but informal numeracy activities significantly less often than both literacy and spatial ($p < .001$).

Table 3
Descriptive Statistics

Outcome	*N*	*Mean*	*SD*	*Min*	*Max*
Frequency					
Spatial Formal	102	28.8	5.3	17.0	40.0
Spatial Informal	102	34.6	3.8	21.0	40.0
Numeracy Formal	103	31.7	4.0	22.0	40.0
Numeracy Informal	103	28.1	4.4	16.0	37.0
Literacy Formal	98	34.7	3.9	19.0	40.0
Literacy Informal	98	34.9	3.2	26.0	40.0
Importance					
Spatial	104	18.1	3.7	9.0	25.0
Numeracy	104	18.2	4.2	8.0	25.0
Literacy	104	19.6	4.37	5.0	25.0
Life Skills	104	18.6	3.22	10	25.0
Anxiety					
Spatial	93	24.7	9.6	8.0	40.0
Mathematics	93	24.8	9.3	9.0	44.0

Teachers' Perceptions on the Importance of Spatial Skills in the Classroom

A repeated measures ANOVA with subject (spatial, numeracy, literacy, life skills) as the independent variable revealed a significant difference in how teachers rated the importance of different subjects, $F(3,309) = 6.79$, $p < .001$, $\eta p^2 = 0.062$ (G.G). Bonferroni pairwise comparisons found teachers rated literacy as significantly more important than both spatial skills ($p = .003$) and numeracy skills ($p < .001$). There was no significant difference in the importance ratings teachers gave for spatial and numeracy skills ($p = 1.000$), spatial and life skills ($p = 1.000$), numeracy and life skills ($p = 1.000$), or literacy and life skills ($p = .098$) (see Figure 3).

Predictors of Teachers' Reported Spatial Activity Use in the Classroom

Linear regression models explored predictors of reported spatial activity use in the classroom (see Table 5). In Model 1, reported formal spatial activity use was the outcome. In step 1, the control variables (mathematics anxiety, years of teaching experience) were added and explained 1.39% of the variation, $F(2,89) = 1.64$, $p = .200$. Spatial anxiety and spatial importance were added in step 2 and explained an additional 12.53% of the variation, $F(4,87) = 4.67$, $p = .002$. Mathematics anxiety and spatial importance were significant predictors in the final model.

Model 2 included reported *informal* spatial activity use as the outcome variable. In step 1, the same control variables

Table 4
Unadjusted Pearson's Correlations

	Life skills importance	*Literacy importance*	*Numeracy importance*	*Spatial importance*	*Formal numeracy*	*Informal numeracy*	*Formal spatial*	*Informal spatial*	*Formal literacy*	*Informal literacy*	*Maths anxiety*	*Spatial anxiety*
Years of teaching	−0.21 (.033) *	0.03 (.800)	0.11 (.263)	0.04 (.699)	0.06 (.524)	−0.10 (.308)	0.03 (.765)	−0.003 (.974)	0.194 (.058)	−0.150 (.141)	0.125 (.235)	−0.084 (.423)
Life skills importance		0.40 (< .001) ***	0.41 (< .001) ***	0.41 (< .001) ***	0.33 (< .001) ***	0.11 (.293)	0.07 (.479)	0.10 (.336)	0.19 (.069)	0.09 (.398)	−0.13 (.203)	−0.01 (.919)
Literacy importance			0.78 (< .001) ***	0.46 (< .001) ***	0.30 (.002) **	0.01 (.928)	0.13 (.206)	0.14 (.159)	0.33 (< .001) ***	0.08 (.410)	−0.22 (.032) *	−0.10 (.364)
Numeracy importance				0.60 (< .001) ***	0.40 (< .001) ***	0.06 (.543)	0.11 (.284)	0.09 (.363)	0.44 (< .001) ***	0.16 (.123)	−0.10 (.366)	−0.10 (.357)
Spatial importance					0.24 (.015) *	0.29 (.004) **	0.37 (< .001) ***	0.13 (.198)	0.18 (0.078)	0.26 (0.011) **	−0.02 (.822)	0.01 (.910)
Formal numeracy						0.38 (< .001) ***	0.20 (.044) *	0.02 (.847)	0.50 (< .001) ***	0.30 (.003) **	0.03 (.798)	−0.04 (.674)
Informal numeracy							0.52 (< .001) ***	0.19 (.066)	0.11 (.287)	0.50 (< .001) ***	0.18 (.092)	0.18 (.090)
Formal spatial								0.18 (.071)	0.08 (.415)	0.36 (< .001) ***	0.20 (.052)	0.01 (.897)
Informal spatial									0.14 (.183)	0.34 (< .001) ***	0.13 (.213)	0.34 (.001) ***
Formal literacy										0.30 (.003) **	0.08 (.421)	0.12 (.240)
Informal literacy											0.19 (.064)	0.42 (< .001) ***
Maths anxiety												0.50 (< .001) ***

Note. Controlling for multiple comparisons, the adjusted cut-off for significance would be .001.

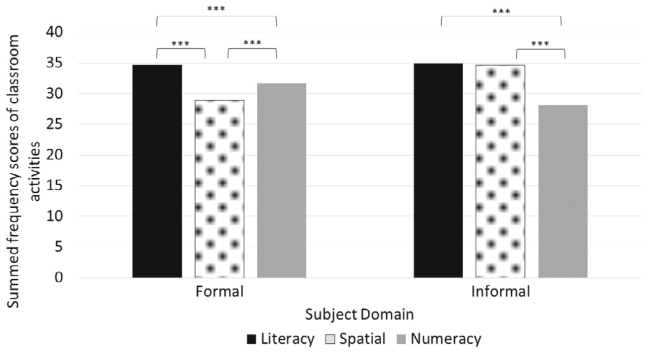

Fig. 2. Use of formal and informal activities in the classroom across different subject domains.

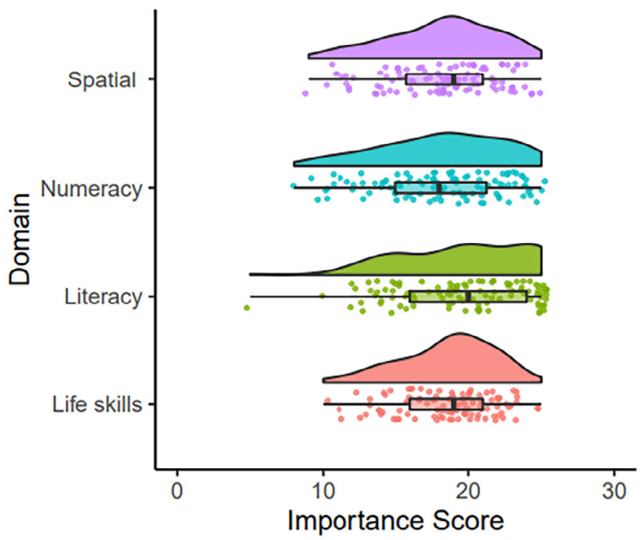

Fig. 3. Teachers perceptions of the importance of different classroom activities.

were added and explained 0.20% of the variation, $F(2, 89) = 1.09$, $p = .340$. Spatial anxiety and spatial importance were added in step 2 and explained an additional 9.85% of the variation, $F(4, 87) = 3.54$, $p = .010$. Spatial anxiety was the only significant predictor in the final model. Note that all VIF and Tolerance collinearity statistics were within the accepted range; Tolerance values >0.2 (Menard, 1995) and VIF scores <10 (Myers, 1990).

DISCUSSION

This study provides a snapshot of teachers' usage and perceptions of spatial activities in practice. It highlights areas in which teacher support, in terms of both training and resources, is required. Teachers reported completing literacy most frequently, followed by spatial, then numeracy activities. These findings mirror evidence that teachers spend less time on mathematics (5–8% of the school day) compared to literacy (21% of the school day; Early et al., 2005). In the current study, we added spatial skills to these comparisons for the first time. Although spatial skill development has not been a key focus in early years curricula, we found that spatial activities are frequently used in the classroom. Promisingly, this suggests that many educators intuitively recognize a value in developing children's spatial skills, even without specific learning goals prompting them to do so. By extension, however, the low frequency of use of numeracy activities is alarming. One explanation could be that teachers and parents are less confident in teaching numeracy due to their own difficulties with mathematics (Costa et al., 2021). The national level of numeracy in the UK is concerningly low, with approximately 20% of 16-to 65-year-olds in England demonstrating numeracy skills akin to a 9-year-old child (National Numeracy, 2020). Could it be that difficulties with mathematics limit teachers in implementing numeracy activities in their teaching?

More detailed insight can be found by comparing formal and informal activity use. For formal activities, literacy was completed most often followed by numeracy, then spatial. If formal activities are driven by the curriculum, it is not surprising that literacy and numeracy have more prominence. Prioritizing literacy and numeracy over spatial activities, suggests teachers are formally working towards achieving children's early learning goals. The lack of early learning goals relating to spatial skills may explain why formal spatial activities are completed less often. By comparison, for informal activities, spatial and literacy activities were completed with a similar high frequency, while numeracy activities were less common. Many informal activities may be deemed as "play activities" with fewer progression consequences if they are not included in the classroom. While formal activities are

Table 5
Regression Coefficients for Models Exploring Predictors of Reported Formal (Model 1) and Informal (Model 2) Spatial Activity Use

Predictor	B	Stand B	SE	t	p
Model 1: Predictors of Formal Activity Use					
Step 1					
Mathematics Anxiety	.15	.27	.07	2.33	.022
Years of Teaching	.02	-.04	.07	-0.36	.718
Step 2					
Spatial Anxiety	-.07	-.14	.06	-1.19	.236
Spatial Importance	.52	.14	.09	3.71	<.001
Model 2: Predictors of Informal Activity Use					
Step 1					
Mathematics Anxiety	-.01	-.03	.05	-0.24	.812
Years of Teaching	0	.01	.05	0.10	.919
Step 2					
Spatial Anxiety	.14	.34	.05	3.09	.003
Spatial Importance	.15	.14	.11	1.38	.172

often more structured and have clear correct answers (e.g., number activity books, writing numbers, recognizing letters), informal activities may require greater subject-specific expertise and creativity (e.g., programmable toys, weighing, measuring, and comparing quantities, rhythm games). The lower use of informal numeracy may suggest that teachers in the reception classroom are less confident in engaging in numeracy-based informal activities than those in other domains.

One explanation for the lower use of numeracy (informal) and spatial skills (formal) in the classroom is that teachers receive less support for these domains compared to literacy, for example, continuous professional development, materials, and initial teacher training (Davis, & Spatial Reasoning Study Group, 2015). Additionally, teachers may perceive these activities as less important, and consequently, choose to spend less time on them. Addressing our second aim, teachers rated the development of literacy skills in the reception classroom as significantly more important than spatial and numeracy skills. Literacy was also rated as more important than daily living skills (although not significantly). Findings that teachers and parents perceive literacy as more important than numeracy are again not uncommon (Costa et al., 2021; Early et al., 2005; Napoli, Korucu, Lin, Schmitt, & Purpura, 2021). However, here it is interesting to note that importance scores for spatial and numeracy activities were similar. This is surprising given the strong emphasis on numeracy versus spatial skills in the early years learning goals. Regardless, more work is needed to convince practitioners of the value of numeracy and spatial skills in the early years, so that they are perceived with the same importance as literacy. For children, not attaining the required numeracy and spatial skills in early life may have far-reaching downstream effects, for example, mathematics test performance at age 7 is a predictor of socio-economic status up to 35 years later (Ritchie & Bates, 2013).

Finally, we sought to understand personal characteristics that may explain why some teachers use more spatial activities in their classrooms, compared to others. Teachers had relatively high levels of mathematics and spatial anxiety considering that average scores of 24 equate to “moderate” levels of mathematics anxiety (Hopko et al., 2003), and “a fair amount” of spatial anxiety (Lyons et al., 2018), respectively. Spatial importance (how important teachers perceived spatial thinking to be) and mathematics anxiety were significant predictors of reported formal spatial activity use. While the link between spatial importance and reported spatial activity use seems logical, it is curious that teachers with higher mathematics anxiety completed more spatial activities. One possible explanation is that due to the anxiety that some teachers feel towards teaching mathematics, these teachers may instead favor spatial techniques/approaches for teaching numeracy over numerical approaches. It is well established that those who experience mathematics anxiety often exhibit mathematics avoidance (Choe, Jenifer, Rozek, Berman, & Beilock, 2019). In this way, perhaps formal spatial activities offer a less threatening way of delivering mathematics content for teachers with elevated mathematics anxiety. Conversely, we found that spatial anxiety was the only predictor of reported informal spatial activity use. Teachers with higher spatial anxiety were found to more regularly use informal spatial activities in the classroom, perhaps because informal activities do not require clear correct/incorrect answers but instead are more creative. This means that informal spatial activities may offer an accessible route to embedding spatial elements into teaching. However, further research is required to unpick the nuances of these relations.

This study should be interpreted in the context of its strengths and weaknesses. The study is strengthened by the discrete sub-group of practitioners surveyed, that is, reception teachers. In certain year groups, and for certain topics, specific spatial activities are more/less appropriate, for example, use of building blocks, and picture books are more appropriate in the early years, while tangrams and 3D rotation tools are more appropriate for older age groups. Hence, the year group is likely a confound in previous studies of spatial activity use in the classroom, particularly when surveys of specific spatial activities are included. By focusing on the reception year only, with a diverse sample of practitioners (from settings across the UK, and with varied levels of classroom experience), we enhance the usefulness of the findings as a basis for informing teaching and practice.

Conversely, the restricted sample means that these findings are not applicable to other year groups. However, this study can provide a template for future research exploring spatial activity use in the classroom with practitioners from other year groups. Another limitation is the use of self-report measures and the potential for bias in how participants remember and perceive their own practice (Schwarz, 1999). While this study provides valuable insight into practitioner’s activities, classroom observations could provide richer insights into spatial skills in teaching practice. Furthermore, although we have described spatial and numeracy activities as separate entities throughout, spatial thinking is recruited in the completion of some formal and informal numeracy activities, for example, physical manipulatives may be used to support counting. However, in our survey, we were interested to see how often specific activities were completed in the classroom and as such any indirect use of spatial thought in numeracy activities is not relevant here.

Another potential limitation of this study is that we did not measure general anxiety. Although previous research has shown that spatial, mathematics, and general anxiety are distinct constructs (Malanchini et al., 2017), and similar effects of general anxiety would be expected across both spatial and mathematics anxiety measures, it is still possible that general anxiety could drive some of the associations between spatial and mathematics anxiety, and other measures. Finally, owing to its associational design, we can only infer directions of causality. Any proposed explanations for observed correlations are inferential only and should be interpreted as such.

Findings from activity use and perceived importance show that spatial and numeracy sub-domains are often overlooked when compared to literacy. However, given the lack of focus on spatial skills in the English curriculum, the frequency of reported spatial activity use was encouragingly high. In the context of the ongoing technological revolution and the need for improving the STEM skills of the workforce, these findings highlight a need to elevate teacher's understanding of the importance of developing children's early spatial and numeracy skills. This may start with efforts to reduce teacher's spatial and mathematics anxiety and educate them on how best to incorporate spatial skills into their teaching (e.g., spatial reasoning toolkit see Gifford et al., 2022).

ACKNOWLEDGMENTS—The contributions of AB and DW were funded by the Helen Hamlyn Trust.

CONFLICT OF INTEREST

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

REFERENCES

Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology. General*, *130*(2), 224–237.

Atit, K., Power, J. R., Pigott, T., Lee, J., Geer, E. A., Uttal, D. H., … Sorby, S. A. (2022). Examining the relations between spatial skills and mathematical performance: A meta-analysis. *Psychonomic Bulletin & Review*, *29*, 699–720. https://doi.org/10.3758/s13423-021-02012-w

Atit, K., & Rocha, K. (2021). Examining the relations between spatial skills, spatial anxiety, and K-12 teacher practice. *Mind, Brain, and Education*, *15*(1), 139–148. https://doi.org/10.1111/mbe.12274

Baroody, A. J., & Li, X. (2009). Mathematics instruction that makes sense for 2 to 5-year olds. In E. L. Essa, & M. M. Burnham (Eds.), *Informing our practice: Useful research on young children's development*. (pp. 119–135). Washington DC, USA: National Association for the Education of Young Children.

Bates, K. E., Williams, A. Y., Gilligan-Lee, K. A., Gripton, C., & Farran, E. K. (2022). Practitioner's perspectives on spatial reasoning in educational practice from birth to 7 years. *British Journal of Educational Psychology*. https://doi.org/10.1111/bjep.12579

Bower, C., Odean, R., Verdine, B. N., Medford, J. R., Marzouk, M., Golinkoff, R. M., & Hirsh-Pasek, K. (2020). Associations of 3-year-olds' block-building complexity with later spatial and mathematical skills. *Journal of Cognition and Development*, *21*(3), 383–405.

Caprara, G. V., Barbaranelli, C., Steca, P., & Malone, P. S. (2006). Teachers' self-efficacy beliefs as determinants of job satisfaction and students' academic achievement: A study at the school level. *Journal of School Psychology*, *44*(6), 473–490.

Carey, E., Hill, F., Devine, A., & Szűcs, D. (2017). The modified abbreviated math anxiety scale: A valid and reliable instrument for use with children. *Frontiers in Psychology*, *8*, 11. https://doi.org/10.3389/fpsyg.2017.00011

Choe, K. W., Jenifer, J. B., Rozek, C. S., Berman, M. G., & Beilock, S. L. (2019). Calculated avoidance: Math anxiety predicts math avoidance in effort-based decision-making. *Science Advances*, *5*(11), eaay1062. https://doi.org/10.1126/sciadv.aay1062

Costa, H. M., Outhwaite, L. A., & Van Herwegen, J. (2021). Preschool Teachers' training, beliefs and practices concerning mathematics in pre-schools in the UK: Implication for education and practice. *Psyarxiv*. Preprint. https://doi.org/10.31234/osf.io/rdx6c

Davis, B., & Spatial Reasoning Study Group. (2015). *Spatial reasoning in the early years: Principles, assertions, and speculations*. Routledge.

Department for Education. (2017). *Statutory framework for the Early Years Foundation Stage*. https://www.foundationyears.org.uk/files/2017/03/EYFS_STATUTORY_FRAMEWORK_2017.pdf

Department for Education. (2021). *Statutory framework for the Early Years Foundation Stage*. https://www.gov.uk/government/publications/early-years-foundation-stage-framework–2

Early, D., Barbarin, O., Bryant, D., Burchinal, M., Chang, F., Clifford, R., … Barnett, W. S. (2005). Prekindergarten in eleven states: NCEDL's Multi-State Study of Pre-Kindergarten and Study of State-Wide Early Education Programs (SWEEP). https://fpg.unc.edu/sites/fpg.unc.edu/files/resources/reports-and-policy-briefs/NCEDL_PreK-in-Eleven-States_Working-Paper_2005.pdf

Fang, Z. (1996). A review of research on teacher beliefs and practices. *Educational Research*, *38*(1), 47–65. https://doi.org/10.1080/0013188960380104

Ferguson, A. M., Maloney, E. A., Fugelsang, J., & Risko, E. F. (2015). On the relation between math and spatial ability: The case of math anxiety. *Learning and Individual Differences*, *39*, 1–12.

Field, A. (2013) *Discovering statistics using IBM SPSS statistics: And sex and drugs and rock "N" roll*. (4th ed.). London: Sage.

Gagnier, K., Holochwost, S., & Fisher, K. (2022). Spatial thinking in science, technology, engineering, and mathematics: Elementary teachers' beliefs, perceptions, and self-efficacy. *Journal of Research in Science Teaching*, *59*(1), 95–126. https://doi.org/10.1002/tea.21722

Gifford, S., Gripton, C., Williams, H., Lancaster, A., Bates, K. E., Williams, A. Y., … Farran, E. K. (2022). *Spatial Reasoning in early childhood*. https://doi.org/10.31234/osf.io/jnwpu

Gilligan, K. A., Flouri, E., & Farran, E. K. (2017). The contribution of spatial ability to mathematics achievement in middle childhood. *Journal of Experimental Child Psychology*, *163*, 107–125. https://doi.org/10.1016/j.jecp.2017.04.016

Gilligan, K. A., Hodgkiss, A., Thomas, M. S., & Farran, E. K. (2019). The developmental relations between spatial cognition and mathematics in primary school children. *Developmental Science*, *22*(4), e12786.

Gilligan-Lee, K. A., Hawes, Z. C. K., & Mix, K. S. (2022). Spatial thinking as the missing piece in mathematics curricula. *NPJ Science of Learning*, *7*, 10. https://doi.org/10.1038/s41539-022-00128-9

Ginsburg, H. P., Lee, J. S., & Boyd, J. S. (2008). Mathematics education for young children what it is and how to promote it. *Social Policy Report—Giving Child and Youth Development Knowledge Away*, *22*(1), 1–24.

Gray, P. (2015) *Free to learn: Why unleashing the instinct to play will make our children happier, more self-reliant, and better students for life*. New York, USA: Basic Books.

Gunderson, E. A., Ramirez, G., Beilock, S. L., & Levine, S. C. (2013). Teachers' spatial anxiety relates to 1st- and 2nd-Graders' spatial learning. *Mind, Brain, and Education*, *7*, 196–199. https://doi.org/10.1111/mbe.12027

Hawes, Z., Gilligan-Lee, K. A., & Mix, K. S. (in press). Infusing spatial thinking into middle school mathematics: What, why, and how? In K. M. Robinson, D. Kostopoulos & A. Dubé (Eds.), *Mathematical learning and cognition in middle childhood and early adolescence: Integrating interdisciplinary research into practice*. Springer Nature Publishing.

Hawes, Z. C., Gilligan-Lee, K. A., & Mix, K. S. (2022). Effects of spatial training on mathematics performance: A meta-analysis. *Developmental Psychology*, *58*(1), 112–137. https://doi.org/10.1037/dev0001281

Hodgkiss, A., Gilligan, K. A., Tolmie, A. K., Thomas, M. S., & Farran, E. K. (2018). Spatial cognition and science achievement: The contribution of intrinsic and extrinsic spatial skills from 7 to 11 years. *British Journal of Educational Psychology*, *88*(4), 675–697. https://doi.org/10.1111/bjep.12211

Hopko, D. R., Mahadevan, R., Bare, R. L., & Hunt, M. K. (2003). The abbreviated math anxiety scale (AMAS): Construction, validity, and reliability. *Assessment*, *10*(2), 178–182. https://doi.org/10.1177/1073191103010002008

Husain, F., Chidley, S., Piggott, H., Averill, P., Basi, T., Gilbert, A., … Corteen, E. (2019). Early Years Foundation Stage Profile (EYFSP) reforms. Pilot report, October 2019. https://dera.ioe.ac.uk/34478/1/Early_Years_Foundation_Stage_Profile_%28EYFSP%29_Reforms.pdf

Lyons, I., Ramirez, G., Maloney, E., Rendina, D., Levine, S., & Beilock, S. (2018). Spatial anxiety: A novel questionnaire with subscales for measuring three aspects of spatial anxiety. *Journal Of Numerical Cognition*, *4*(3), 526–553. https://doi.org/10.5964/jnc.v4i3.154

Malanchini, M., Rimfeld, K., Shakeshaft, N. G., Rodic, M., Schofield, K., Selzam, S., … Kovas, Y. (2017). The genetic and environmental aetiology of spatial, mathematics and general anxiety. *Scientific Reports*, *7*(1), 1–11.

Menard, S. (1995) *Applied Logistic Regression Analysis*. Sage University Paper Series on Qualtitative Applications in the Social Sciences, 07-106, Thousand Oaks, CA: Sage.

Mix, K. S., Levine, S. C., Cheng, Y.-L., Young, C., Hambrick, D. Z., Ping, R., & Konstantopoulos, S. (2016). Separate but correlated: The latent structure of space and mathematics across development. *Journal of Experimental Psychology: General*, *145*(9), 1206–1227. https://doi.org/10.1037/xge0000182

Myers, R. H. (1990). *Classical and modern regression with applications* (Vol. 2, p. 488). Belmont, CA: Duxbury press.

Napoli, A. R., Korucu, I., Lin, J., Schmitt, S. A., & Purpura, D. J. (2021). Characteristics related to parent-child literacy and numeracy practices in preschool. *Frontiers in Education*, *6*, 54. Frontiers. https://doi.org/10.3389/feduc.2021.535832

National Numeracy. (2020). Our impact in focus 2020–2021. https://www.nationalnumeracy.org.uk/sites/default/files/2021-02/National%20Numeracy′s%20Impact%20in%20Focus%202020-21.pdf

Ritchie, S. J., & Bates, T. C. (2013). Enduring links from childhood mathematics and reading achievement to adult socioeconomic status. *Psychological Science*, *24*(7), 1301–1308. https://doi.org/10.1177/0956797612466268

Schwarz, N. (1999). Self-reports: How the questions shape the answers. *American Psychologist*, *54*(2), 93–105. https://doi.org/10.1037/0003-066X.54.2.93

Upadyaya, K., & Eccles, J. S. (2014). How do Teachers' beliefs predict Children's interest in math from kindergarten to sixth grade? *Merrill-Palmer Quarterly*, *60*(4), 403–430. https://doi.org/10.13110/merrpalmquar1982.60.4.0403

van Doorn, J., van den Bergh, D., Böhm, U., Dablander, F., Derks, K., Draws, T., … Wagenmakers, E. J. (2021). The JASP guidelines for conducting and reporting a Bayesian analysis. *Psychonomic Bulletin & Review*, *28*(3), 813–826.

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

Zosh, J. M., Hirsh-Pasek, K., Hopkins, E. J., Jensen, H., Liu, C., Neale, D., … Whitebread, D. (2018). Accessing the inaccessible: Redefining play as a spectrum. *Frontiers in Psychology*, *9*, 1124. https://doi.org/10.3389/fpsyg.2018.01124

APPENDIX

See Table A1.

Table A1
Reliability Co-Efficient Scores (Cronbach's Alpha) for Each Dependent Measure

Measure	*Cronbach's Alpha*
Life skills importance	0.731
Literacy importance	0.921
Numeracy importance	0.851
Spatial importance	0.805
Formal numeracy frequency	0.665
Informal numeracy frequency	0.710
Formal spatial frequency	0.766
Informal spatial frequency	0.672
Formal literacy frequency	0.540
Informal literacy frequency	0.506
Maths anxiety	0.922
Spatial anxiety	0.954