Introducing the Spatial Reasoning Toolkit for Early Childhood Education: An evaluation of the use and impact of the toolkit on practitioner's and children's spatial and mathematics learning

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Data availability statement

Unfortunately, we do not have ethical approval to share the research data.

Abstract

Background: Despite empirical evidence that spatial reasoning is important for developing children's mathematics understanding, spatial reasoning is underrepresented in mathematics curricula and practice in England.

Aims: We aimed to document the use and impact of the Spatial Reasoning Toolkit (SRT), with a focus on practitioners. The SRT is a collection of resources which translate research into practice for practitioners who work with children from birth to 7 years.

Sample: Participants were early childhood education (ECE) practitioners working in England with children from birth to 7 years who completed a questionnaire (Study 1; N=99), focus groups or case study interviews (Study 2, N=13)

Methods: This was a mixed methods research project including a questionnaire, focus groups and case study interviews.

Results: The Spatial Reasoning Toolkit (SRT) was being used by practitioners in a variety of roles for different teaching and learning purposes. The resources were reported to have improved practitioners' confidence in defining spatial reasoning and children's spatial reasoning and confidence in mathematics.

Conclusion: Evidence-based tools designed to meet the needs of practitioners can support the translation of research findings into educational practice. The SRT is an important resource for educational practitioners for supporting the development of children's spatial reasoning and confidence in mathematics.

Keywords: spatial reasoning, research-based tools, mathematics education, early years

Introducing the Spatial Reasoning Toolkit for Early Childhood Education: An evaluation of the use and impact of the toolkit on practitioner's and children's spatial and mathematics learning

Spatial reasoning describes a range of abilities that are related to understanding the properties of objects (shape, size, orientation) and the relationship between objects. Spatial reasoning is important in our everyday lives, facilitating key skills such as navigation, positioning and perspective taking. Research evidence also shows it is strongly associated with mathematics learning (Atit et al., 2021; Gilligan et al., 2019; Hawes et al., 2022; Mix et al., 2016; Verdine et al., 2014). For several years, education policy in England has understated the importance of spatial reasoning in favour of number in the statutory early years and primary mathematics curricula (Gilligan-Lee et al., 2022; Ofsted, 2017). Whilst the Early Years Statutory Framework (DfE, 2023, p. 10) mentions spatial reasoning in the Mathematics Education Programme, the previous “Shape, Space and Measures” Early Learning Goal (the statutory assessment benchmark for end of the school year in which children are four to five years old) has been removed. For primary school children (aged 5-to-11 years), a similar lack of emphasis on embedding spatial reasoning is apparent. The primary curriculum includes teaching of shape, position, and direction, but influential spatial concepts such as scaling, rotation or perspective taking are not specifically referenced (Gilligan-Lee et al., 2022). Furthermore, Gilligan-Lee and colleagues’ (2022) research also indicates that practitioners perceive spatial reasoning activities as significantly less important than non-spatial subjects. Practitioners have also reported an absence of training on how to develop children’s spatial reasoning (Gripton et al., under review).

Seeking to address this gap in training and understanding, a group of researchers and practitioners developed an evidence-based set of resources, The Spatial Reasoning Toolkit (SRT)

(Gifford et al., 2022), to support adults working in England with children from birth to 7 years (although the resources are applicable to many early years settings). The aim of this study is to examine the use and impact of the SRT a year after its launch.

What is spatial reasoning?

Spatial reasoning is a complex cognitive process incorporating many potentially unrelated skills (Hawes et al., 2023). Key aspects of spatial reasoning included in the SRT are position, direction, navigation, orientation, shapes of objects, shape properties and spatial structure, composition and decomposition of shapes, movement and rotation, symmetry, perspective-taking, and scaling (Gifford et al., 2022). These spatial skills can be defined in two domains: intrinsic - skills that focus on 'within object' understanding such as mental rotation and shape properties, and extrinsic – aspects that help us understand the relationship 'between objects' like navigation and spatial scaling (Newcombe & Shipley, 2015).

Spatial reasoning is malleable (Baenninger & Newcombe, 1989; Uttal, et al., 2013) and training effects can be observed in young children, older children, and adults (Hawes et al., 2022; Uttal, et al., 2013; Yang et al., 2020). Spatial training, particularly in spatial visualisation abilities like mental rotation (Hawes et al., 2015; McDougal et al., 2023), has consistently been shown to improve children's mathematics skills (see Hawes et al., 2022 for a meta-analysis). There is provisional evidence that this may be particularly true for children from low socioeconomic backgrounds (Bower et al., 2020; Gilligan-Lee et al., 2023a; Schmitt et al. 2018). Spatial activities are highly engaging and enjoyable for children (Koç & Koç, 2023), thus providing an accessible and effective way of teaching mathematics.

Spatial reasoning and mathematics

Empirical studies have pointed to a causal effect of spatial training on children's mathematics skills in both young children (Bower et al., 2020) and children of primary school age (Hawes et al., 2015). A meta-analysis of 29 studies that used controlled pre-post-test designs showed an average effect size of 0.28 (Hedge's g) of spatial training on mathematics understanding (Hawes et al., 2022). Compared to equivalent cognitive training programmes on mathematics understanding in comparable age groups, this result suggests a substantially larger effect for spatial training (Hawes et al., 2023). Most of the studies analysed by Hawes et al. (2022) trained children aged 6-14 years, so caution should be operated in translating these gains to younger children, although other meta-analyses have found no effect of age on training gains (Atit et al., 2021). Finding effective ways to support the training of spatial reasoning in education settings with young children is essential to supporting greater understanding of mathematics.

There are four key arguments presented to explain why spatial reasoning and mathematics are associated (see Hawes et al., 2023). First, neural evidence suggests similarities in brain area activation when engaging in spatial and numerical thinking (Hawes & Ansari, 2020). Second, mathematics is inherently spatial – curriculum topics such as geometry and measurement involve numbers related to space. Spatial reasoning is also applied in topics such as place value, where children need to recognise the spatial positioning of tens and units to decide if a number is larger or smaller than another (see Mix, 2019). Third, spatial visualisation is thought to help children operate a "mental blackboard" to support mathematical problem solving (Bates et al., 2021; Hawes et al., 2023). Finally, the solving of mathematics problems is often facilitated by spatial representations. Resources such as number frames and lines, rulers and protractors are used to support mathematical understanding (Mix, 2010).

Supporting Practitioners to Embed Spatial Reasoning

Research suggests that practitioners are not sufficiently equipped to embed spatial reasoning into practice (Moss et al., 2015). Practitioners working across the birth to 7 years age group in England have reported receiving little or no training in spatial reasoning (Bates et al., 2023; Gripton et al., under review). Practitioner feedback has also suggested that, for some, confidence in explaining spatial reasoning to others is low (Bates et al., 2023) and anxiety about spatial reasoning (and mathematics) is at a moderate level (Gilligan-Lee et al., 2023b). It is well understood that practitioner beliefs and perceptions can impact classroom practice (Fang, 1996; Caprara et al., 2006). A study of ECE practitioners in England reported that they perceived spatial reasoning (and mathematics) skills as less important than literacy skills (Gilligan-Lee et al., 2023b). Furthermore, Atit and Rocha (2020) identified a positive relationship between practitioners 'spatial skills and their use of spatial tools in practice. Increasing practitioners' understanding of spatial reasoning could be a good first step in improving children's spatial reasoning.

Evidence from spatial reasoning training programmes that incorporated professional development and practitioner-led interventions provide reassurance that research can be translated into practice, albeit under research conditions (see Hawes et al., 2017; Lowrie et al., 2017; 2018; Mulligan et al., 2020; Lowrie & Logan, 2023). As an example, Lowrie and colleagues (2017) provided a five-day training workshop to practitioners, prior to practitioners delivering a 10-week spatial intervention programme in place of measurement and geometry lessons. The intervention resulted in children outperforming the control group on spatial reasoning and mathematics measures. Additionally, a recent qualitative study provides early evidence that supporting practitioners with professional development can also lead to positive impacts on practitioners' and children's spatial reasoning in a more naturalistic application; two teachers, working with 29 4- to 6-year-olds, were supported with a professional development programme in spatial orientation including a learning trajectory (Koç & Koç, 2023). The practitioners incorporated the development steps and activities from the programme into their planning and practice over a five-month period. Results included practitioners developing a greater understanding of spatial orientation and increased children's engagement in spatial tasks.

Turning research into practice is a complex journey and requires systematic development in consultation with practitioners (Burkhardt & Schoenfeld, 2021). Effective initiatives translate established findings into accessible resources presented via reputable, credible partners (Gorard et al., 2020) also referred to as 'knowledge brokers' (Ryecroft-Smith, 2022; Malin & Brown, 2020). However, as Burkhardt & Schoenfield (2003) highlight, these tools and processes are rare in education. Here we evaluate the SRT as one such educational tool.

The Spatial Reasoning Toolkit

Launched in February 2022, the SRT (Gifford et al., 2022) was created to develop practitioners' understanding of spatial reasoning and allow them to apply evidence from research alongside their professional judgement and knowledge of the children in their setting (Gripton et al., under review). The resources aimed to help practitioners identify opportunities in their current practice to support children's spatial reasoning. At launch, the SRT included: a research summary, a trajectory of spatial reasoning development, posters, videos, and children's book ideas (www.earlymaths.org/spatial-reasoning). All the materials were hosted on the website of the Early Childhood Maths Group, an organisation of mathematics experts and enthusiasts focused on providing guidance to adults working with young children (www.earlymaths.org). The resources were designed and refined following feedback from practitioners (Bates et al., 2023; Gripton et al., under review). The key elements identified were that the resources needed to be multi modal, age-related and accessible to practitioners to facilitate their adoption (Gripton et al., under review).

The current study

This study explored how the SRT was being used by practitioners working with children from birth to 7 years in England and if the content has stimulated any impact for the target audiences. The period under review was the first year of launch (28th February 2022 – 28th February 2023). The following research questions (RQ) were explored across two studies.

RQ 1: How has the SRT been used by practitioners in England working with children from birth to 7 years?

RQ2: What impact has the SRT had on:

- practice,
- curriculum development, and
- children?

Study 1 aimed to gather feedback from a wide variety of practitioners via an online questionnaire. Study 2 involved online focus groups and case studies with practitioners to explore their use (and non-use) of the SRT and any resulting changes in more detail.

Study 1: Practitioner Use of the SRT and the Impact on Practice

Materials and methods

This study aimed to provide a quantitative analysis of how practitioners used the SRT and its impact.

Participants

Participants from England, working with children aged from birth to 7 years, were recruited from mailing lists, social media, and researcher's networks to participate in an online questionnaire. 99 practitioners responded to the recruitment. 11 were outside of England so did not proceed to complete the questionnaire. A further 20 did not progress past the demographic questions. The remaining 68 practitioners completed at least one question in the survey and were included in our analysis. Respondents received a set of spatial reasoning keyrings as an incentive for participation. The study received University ethical approval and all participants provided consent to take part.

Most participants reported their main role as working in a reception class in a primary school (*n* = 33, 48.53% of sample). See Figure 1 for a breakdown of roles reported. Participants' average length of experience in education was 17.49 years (*SD* = 9.21 years). Practitioners were grouped on their use of the Spatial Reasoning Toolkit: Non-User (*n* = 9, 13% of sample) Novice User (*n* = 27, 40% of sample), Apprentice User (*n* = 27, 40% of sample) and Expert User (*n* = 5, 7% of sample). See Table 1 for definitions of user types.

Figure 1

Main Job Role Reported by Practitioners

Table 1

Categories of Toolkit User

Toolkit User Type	Definition
Expert users	Using the SRT regularly to integrate spatial reasoning into practice
Apprentice users	Using the SRT for lesson ideas
Novice users	Considering how to use the SRT
Non-users	Practitioners who knew of the SRT but had not used it

Procedure

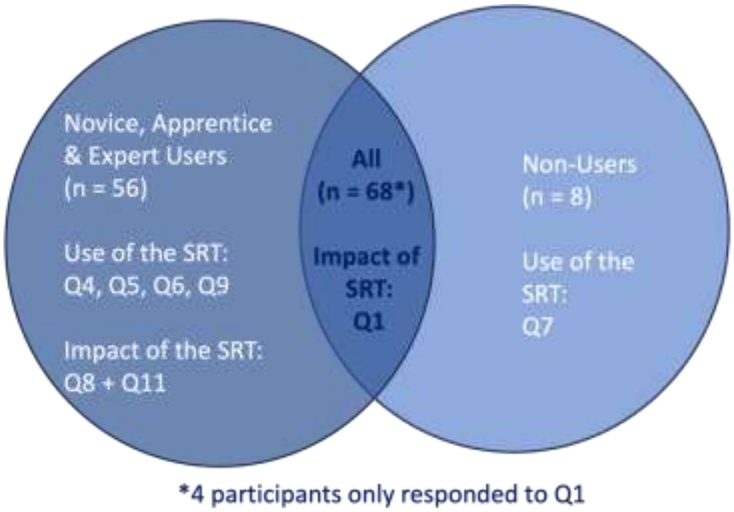
A Qualtrics online questionnaire (see supplementary information) was developed to investigate the use of the SRT amongst practitioners and the impact on their practice and the children they work with. The questionnaire was designed to capture responses from practitioners actively using the SRT and those who had not used it, one year after launch. For those who had used the SRT, the survey included 16 questions taking 15 minutes to complete. For participants who had not used the SRT, a set of five questions was presented taking 5 minutes to complete.

Five questions in the survey were on the use of the SRT (Q4, Q5, Q6 and Q9 for those who had used the SRT and Q7 for non-users). Three questions were focused on the impact of the SRT on practitioners and the children they worked with (Q1, Q8 and Q11). Q1, which asked participants to rate their level of confidence in explaining spatial reasoning, was presented to all participants, Q8 and Q11 were only presented to those who had used the Toolkit. The remaining questions, not reported here, explored the training needs of practitioners, and gathered feedback on any improvements that could be made to the resources. Those questions were presented to all groups.

For a visual representation of which questions were presented to which group and the number of participants responding see Figure 2.

Figure 2

Participant Groups and the Questions Answered



Results

Analysis

All data analysis was completed using Jamovi. Tests of normality indicated that all data did not fit a normal distribution (*ps* < .001). Non-parametric analyses were therefore applied. Of the 68 participants, four did not respond to all the questions and were therefore removed from the analyses except for Q1.

Descriptive Statistics

Use of the Toolkit

Participants who had used the SRT (n = 56) found it to be 'very useful' on a scale of 1 (not at all useful) to 5 (extremely useful) (*Mdn* = 4.00, *IQR* = 1.00). The developmental trajectory was identified as the most useful section of the SRT (*n* = 24, 48% of sample). However, all elements of the SRT were perceived useful. The children's book lists and videos had been used by fewer practitioners than the other resources, with the posters and the trajectory of spatial reasoning development reported as the most used (see Figure 3). Practitioners reported that they were using the SRT for a range of purposes. The most frequent response was "To support planning or making choices about provision" (*n* = 48) followed by "For own professional development" (*n* = 44) (see Figure 4)

Practitioners who had not used the Toolkit (*n* = 8) reported 'lack of time' or 'other' as barriers to use. Other barriers included lack of awareness and sharing the Toolkit with other practitioners but not using it themselves.

Figure 3

Practitioner Rating of the Usefulness of Each Section of the SRT

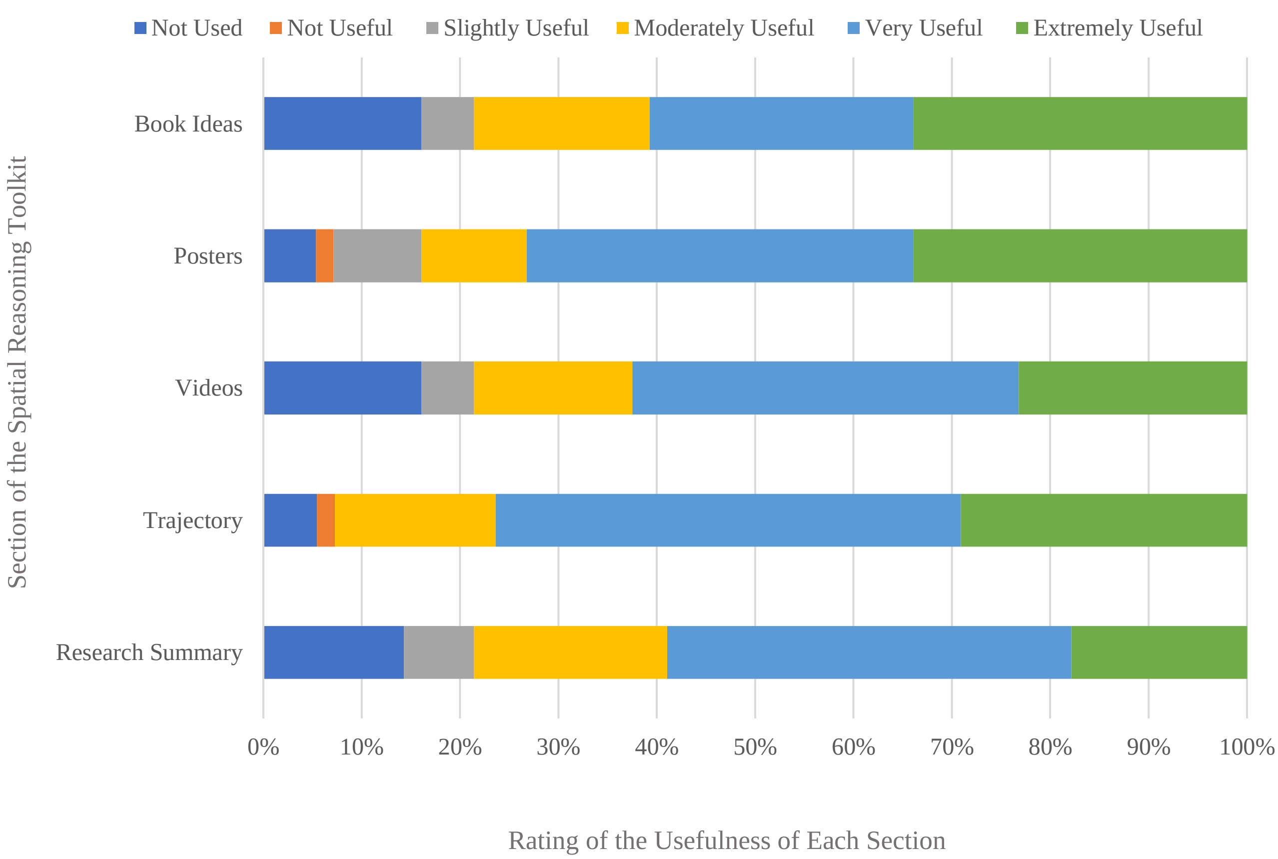
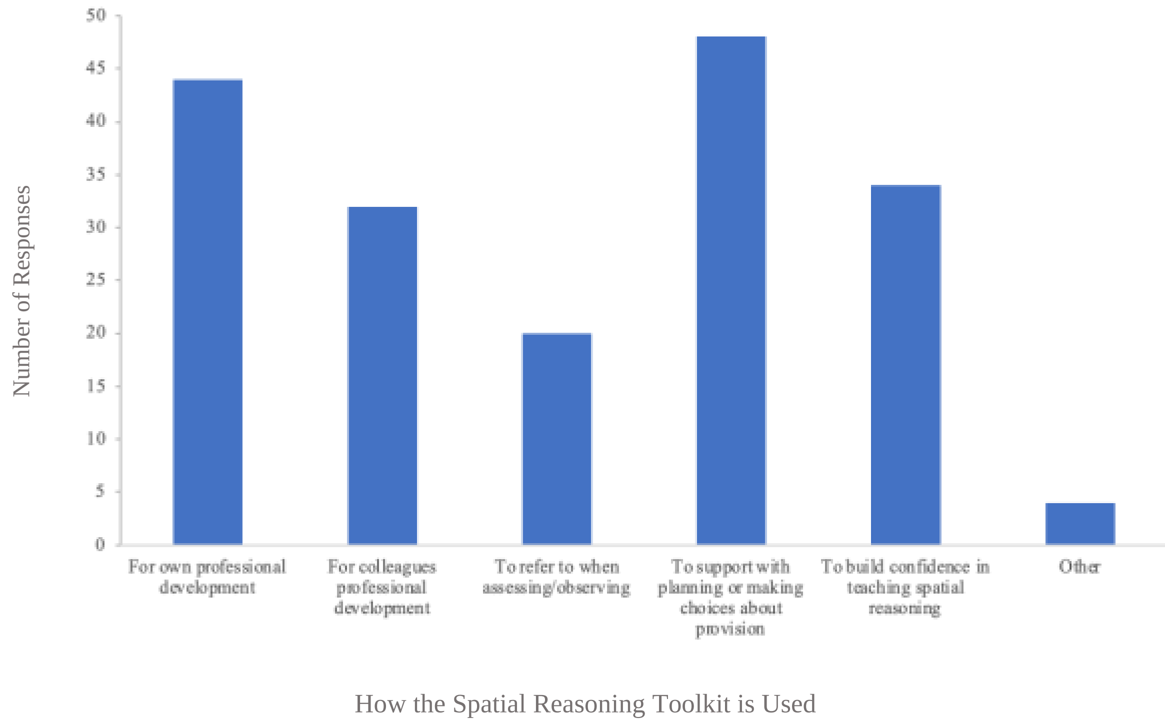


Figure 4

How do you use the Toolkit in Your Practice?



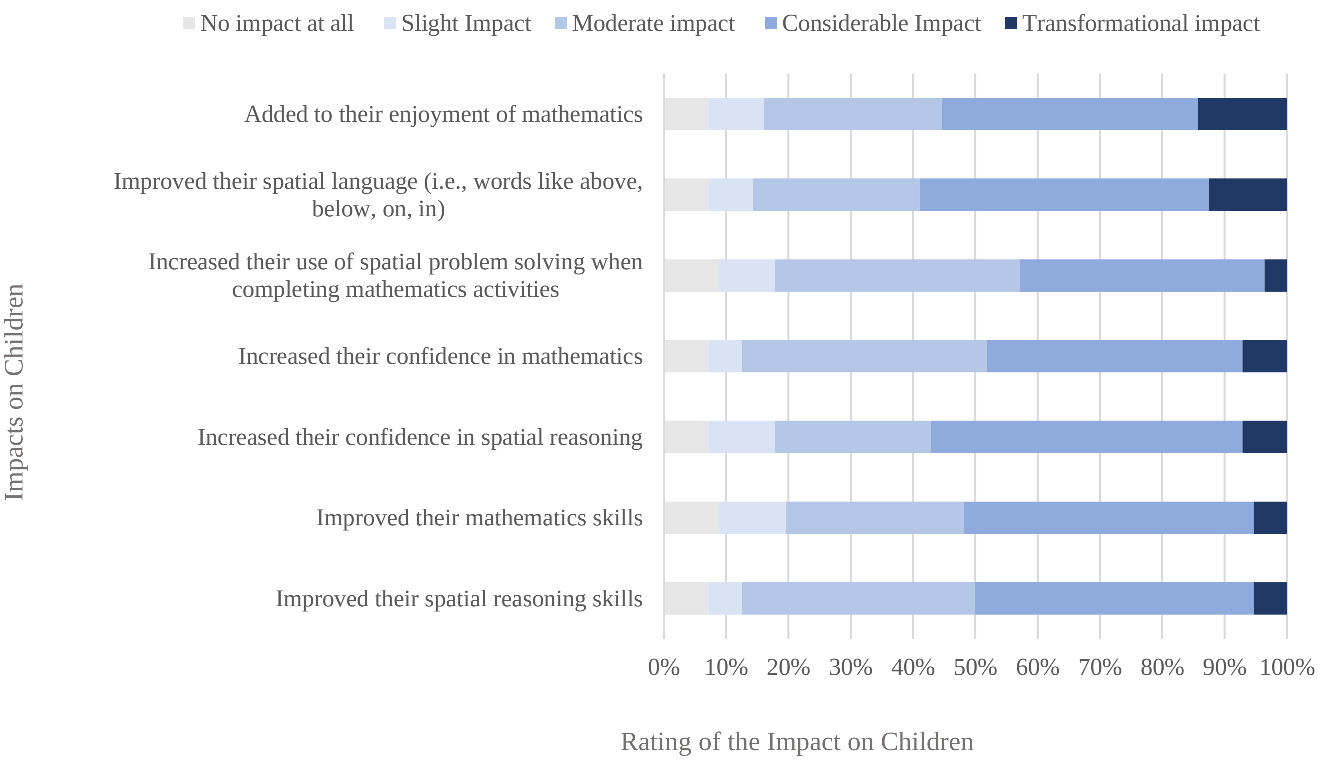
Impact of the Toolkit

Most participants reported that the SRT had a moderate impact on their practice, *Mdn* = 3.00, IQR= 1.00, on a scale of 1 (no impact at all) to 5 (transformational impact). In terms of perceived impact on the children that practitioners worked with, the SRT was rated as having considerable impact on improving children's mathematics skills, increasing their confidence in spatial reasoning, improving their spatial language, and adding to their enjoyment of mathematics (all *Mdn* = 4.00, *IQR* = 1.00). Most respondents rated the improvement of children's spatial reasoning skills as moderate to considerable impact (*Mdn* = 3.50, *IQR* = 1.00). The SRT was rated as having a moderate impact on increasing children's confidence in mathematics and increased use of spatial problem solving when completing mathematics activities (*Mdn* = 3.00, *IQR* = 1.00). See Figure 5.

In response to Q1 which was addressed to all participants regardless of whether they had used the SRT or not, on average, participants reported that they were "a little confident" in explaining Spatial Reasoning to someone else (*Mdn* = 2.00, *IQR* = 1.00) on a scale from one ("not confident at all") to 4 ("very confident").

Figure 5

Perceived impact of the Toolkit on Children



Inferential Statistics

Inferential analysis was completed using the Mann Whitney U test to understand if there were any statistical differences to the usefulness or impact of the SRT based on how much users had engaged with the resources. The dependent variables were the responses to the questions regarding usefulness and impact. The independent variable was the extent to which the participants had used the SRT. Participants were grouped as novice users *(n* = 24) and apprentice/expert users (*n* = 32). Non- users (*n* = 8) were excluded in the analysis of use or impact data but were included by extending the ‘novice users’ group when examining confidence in explaining spatial reasoning (Q1).

Use of the Toolkit

There was no significant difference between how participants rated the usefulness of the SRT based on their use of the resources (*Apprentice/Expert users Mdn* = 4.00, *IQR* = 1.00, *Novice Users Mdn* = 4.00, *IQR* = 0.25, *U* = 316.50, $p = .22$, $r_{rb} = 0.18$).

Impact of the Toolkit on Practice

Participants who had actively engaged with the SRT as an apprentice or expert user reported significantly more impact on their practice than novice users (*Apprentice/Expert users Mdn* = 4.00, *IQR* = 1.00, *Novice Users Mdn* = 3.00, *IQR* = 0.25, *U* = 199.50, $p < .001$, $r_{rb} = 0.48$).

Impact of the Toolkit on Children

Apprentice and Expert users of the SRT observed a significantly greater impact on improving children’s spatial reasoning skills (*Apprentice/Expert users Mdn* = 4.00, *IQR* = 1.00, *Novice Users Mdn* = 3.00, *IQR* = 1.00, *U* = 273.00, $p = .048$, $r_{rb} = 0.29$) and improving children’s mathematics skills (*Apprentice/Expert users Mdn* = 4.00, *IQR* = 1.00, *Novice Users Mdn* = 3.00, *IQR* = 2.00, *U* = 231.50, $p = .007$, $r_{rb} = 0.40$) than Novice users.

In addition to the above inferential statistics, we also examined the difference in the confidence levels of practitioners in explaining spatial reasoning based on their use of the SRT (Q1). This analysis included those who had not used the Toolkit in the group with the Novice users (Non-user/Novice $n = 36$, Apprentice/Expert users $n = 32$).

Practitioners in the apprentice/expert user category had significantly higher levels of confidence in explaining spatial reasoning than peers who had not used or were just starting to use the Toolkit (A*pprentice/Expert users Mdn* = 3.00, *IQR* = 1.00, *Novice/Non-users Mdn* = 2.00, *IQR* = 1.00, *U* = 370.50, *p* = .005, r_{rb} = 0.36).

Discussion

This study aimed to examine how the SRT had been used and the perceived impact it had on practitioners, the curriculum, and the children they worked with since its launch in February 2022. The Toolkit was rated as ‘very useful’ by all practitioners, regardless of how much they had applied it in practice. All the individual resources were ranked as ‘useful’ to ‘very useful’, with the trajectory of spatial reasoning development being highlighted as the most useful. Learning trajectories have proved a useful tool in supporting the effective implementation of spatial activities into classrooms with young children (Koç & Koç, 2023). Our findings extend this evidence. The favourable rating of all the resources suggests that providing resources in different formats was well received by users. Practitioners and academics have previously reported that multi-modal materials are critical to the adoption of evidence-based tools (Gripton et al., under review; Ryecroft-Smith, 2022). The SRT was being used for a wide range of purposes including planning and making choices about the provision of spatial reasoning activities demonstrating the flexibility of use of the SRT.

In terms of impact of the Toolkit, practitioner confidence levels in explaining spatial reasoning to others were higher in the group of users that had actively engaged with the SRT resources. Despite this only being correlational evidence it is important given our understanding of how practitioner anxiety can relate to children’s understanding of a topic (Atit & Rocha, 2020). For practitioners not using the SRT actively, time constraints were the most reported factor limiting usage. Workload management is increasingly reported to be linked to burnout for adults working in education settings (Jomaud et al., 2021; Lawrence et al., 2019). Thus, further investment of time in distilling the Toolkit's key messages into quickly digestible and accessible materials could potentially widen usage. Practitioners actively engaging with the materials reported more impact on their practice than those not using the resources. In addition, the reported impact on children's understanding of spatial reasoning and mathematics was higher in settings where the SRT was being used. This provides preliminary evidence that the SRT is an effective resource in bridging the gap between research evidence and practice to benefit children. Further research, such as an intervention study would help determine how effective the SRT is compared to other methods for extending children's spatial reasoning skills and enhancing their mathematics understanding.

Study 2: Exploring practitioner views of the SRT and its impact on practitioners and pupils

This study aimed to provide a qualitative analysis of how practitioners used the SRT and its impact on their practice.

Materials and method

Participants

Participants were thirteen practitioners working in England with children aged 3 to 7 years, with an average of 13.8 years' work experience in education (SD = 7.01 years) (see Table x for a demographic breakdown). Participants took part in either a focus group or a semi-structured interview. Focus group participants (*N* = 11) were recruited from mailing lists, researchers' professional networks and social media (i.e., Twitter). Focus groups were recruited to represent three categories of Toolkit user: experts (*N* = 3), apprentices (*N* = 4), and novice (*N* = 4) users. Participants selected their category, in a pre-focus group/interview questionnaire based on the definitions detailed in Table X. All participants received a £50 shopping voucher for their participation. The semi-structured interviews (n = 2) were conducted as part of a case study research project examining how the SRT was being used in different settings. The practitioner interviews are included here to extend the thematic analysis of practitioners' experience of the SRT. Full details of the case studies can be reviewed in Farren et al. (in press).

The study received Favourable Ethical Opinion from the University Ethics Committee and all participants provided written consent to participate, having been provided with information about the study.

Table 1

Participant Demographics

Participant Code	Role	Setting	Years' Experience	Toolkit User Type
P1*	Reception class teacher (and Senior Leader)	Primary School	25	Expert
P2	Reception class teacher (and EYFS Lead)	Primary School	8	Expert
P3	Reception class teacher (and EYFS Lead)	Primary School	6	Expert
P4	Senior Leader and Mathematics Subject Lead	Primary School	19	Apprentice
P5	Reception class teacher (Co-Mathematics Subject Lead)	Primary School	18	Expert
P6	Reception class teacher (and Mathematics Subject Lead)	Primary School	8	Apprentice
P7	Nursery class teacher	Primary School	13	Apprentice

P8	Teacher Educator – Early Years Lead	Teacher Training Provider	15	Apprentice
P9	Key Stage 1 class teacher	Primary School	9.5	Novice
P10	Key Stage 1 class teacher	Primary School	7	Novice
P11	Key Stage 1 class teacher	Primary School	6	Novice
P12	Key Stage 1 class teacher	Primary School	20	Novice
P13*	Key Stage 2 class teacher (and Mathematics Subject Lead)	Special School	25	Apprentice

Note: * = semi-structured interviews

Procedure

The focus groups and interviews used the same question schedule, drawn from the research questions, to facilitate 45-minute discussions (see Appendix 1). Section one of the schedule focused on the use of the Toolkit, section two explored the impact the SRT had on practitioners and the children they work with. Section three included questions on what additional spatial reasoning support practitioners needed. For novice users, questions were adjusted to be applicable to their experience. For example, instead of asking "Which aspects of the Toolkit did you embrace?", novice users were asked "Which element of the Toolkit do you think you would use the most?". The schedule was used as a guide for the discussions and allowed flexibility to allow participants to reflect and permit the discussion to develop organically.

Focus groups and interviews were conducted online, except for one semi-structured interview which was conducted face-to-face as part of a visit to the school setting. All discussions were audio or video recorded and audio files were automatically transcribed using Otter.ai. Transcripts were checked against the recordings for accuracy, and pseudonymised.

Researcher notes were made during and after each focus group or interview. The researcher captured the main points of the discussion and used these notes to provide a summary at the end of each session to allow participants to redirect any misunderstandings. Notes made after the discussion detailed the mood observed in the discussions and the researcher's reflections on any areas of difference in participant views. This allowed the researcher to reflect on each discussion and record any latent meaning and emotional reactions of the participants.

Analysis strategy

The data were analysed using Reflexive Thematic Analysis (RTA) (Braun & Clarke, 2019). RTA is a widely used, theoretically flexible approach that embraces the active role of the researcher in their subjective interpretation of the data (Braun & Clarke, 2021). This was key in this project, given the prior experience of the research team in developing and deploying the SRT in research. Our analysis was approached from an experiential orientation using an inductive approach to the data to identify patterns of meaning across the dataset. This was driven by the exploratory nature of the research questions.

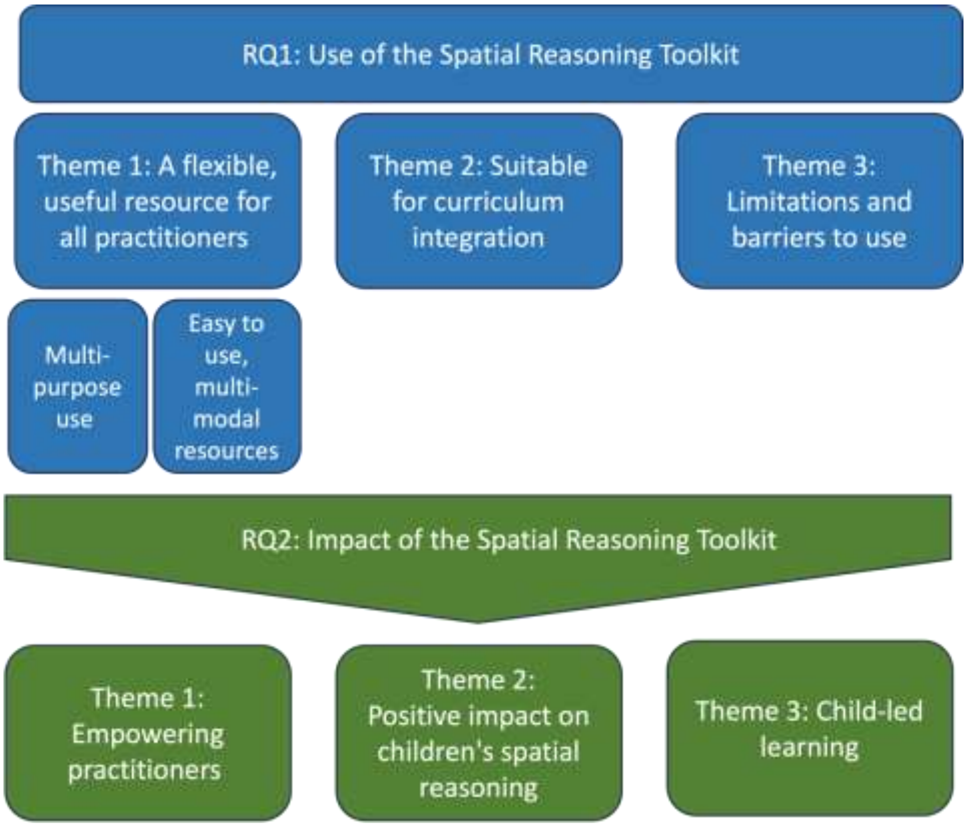
The analysis was completed across the transcripts from five focus groups and two interviews as well as the researcher's notes. The first author familiarised themself with the transcripts by reading them multiple times and watching/listening to the video/audio recordings. They then undertook an iterative coding process and the initial identification of themes. Coding was completed by first annotating salient points on hard copies of the transcripts before using NVivo 12 to inductively code each transcript. Codes reflected semantic and latent meaning. Codes were reflected on and refined to remove duplication and increase meaning. Themes were constructed from the codes in reference to the research questions and organised into two categories: 1. the use of the SRT and 2. the impact of the SRT. Themes were revised in discussion between the researchers (SM & EM and SM & EF), which allowed for the sense checking of ideas and facilitated the exploration of assumptions and interpretations as per Braun & Clarke's (2019, p. 594) guidance. Definitions of these themes were reviewed by SM, EM and EF to ensure meaning was clear and authentically reflected the data.

Results

Six themes were identified, grouped into two categories to address the research questions (see Figure 6). Pseudonymised participant codes are used to identify each quote.

Figure 6

Thematic Map



RQ1: Use of the Toolkit

Theme 1: A flexible, useful resource for all practitioners. This theme captures both feedback on the content within the SRT and the way that content has been used by practitioners. Within this theme we identified two subthemes: *multi-purpose use* and *easy-to-use, multi-modal resources*.

Multi-purpose use: The SRT has been used in a variety of contexts by practitioners in different roles within their organisation. For example, it has allowed mathematics subject leaders in primary schools to support teaching staff across their school, enabling leaders to develop a consistent approach to supporting spatial reasoning learning and provided support for teaching assistants (TAs) who often move around different classrooms and year groups. A mathematics subject leader stated that:

" [lesson cover is often provided] by TAs from the main school who don't necessarily have understanding of what block play can allow and what...can be drawn out of it and the question[s] that they could be asking … Having those actual prompts within the nursery for ... early years teachers ... to like, glance up and... have another idea about what could come next [has been helpful]" (P4).

This demonstrates the value of the Toolkit's flexibility in supporting different types of practitioners to develop children's spatial reasoning development.

Use of the Toolkit has also supported the identification of learning gaps for different pupil groups, such as those deemed disadvantaged[1]. For example, Participant 5 (Table 1) explained how they had used the learning trajectories to benchmark children's spatial reasoning*:*

"We've got quite a lot of disadvantage in our school and in our area. So being able to … closely identify where those gaps might be for those children ... and what sort of experiences they might need to be exposed to, to catch them up. That's been the most useful thing for us." (P5).

Practitioners also discussed how to extend the use of the SRT within their settings. They saw value in the SRT being used to support older children with perceived gaps in their mathematics understanding from year groups beyond the intended birth-to-seven-years age range of the SRT.

[1] Disadvantaged pupils are identified by the Department of Education as those receiving the Pupil Premium Grant. This group is made up of 3 pupil categories: 1. Pupils who are recorded as eligible for free school meals or have been recorded as eligible in the past 6 years, including eligible children of families who have no recourse to public funds (NRPF). 2. Children looked after by local authorities, referred to as looked-after children. 3. Children previously looked after by a local authority or other state care, referred to as previously looked-after children (DfE, 2024)

"I'd really quite like to see the toolkit being run throughout the school and it actually being used for children higher up the school that are missing this foundation" (P3)

"[using it] for our lowest [perceived ability] 20% of children across the school. That's something we're going to look into." (P5)

This shows that although the SRT is already being used flexibly across the school setting, there is scope to extend this further in collaboration with practitioners.

Easy to use, multi-modal resources*:* Practitioners had positive views of the design and structure of the SRT, e.g., the idea suggestions and the colour coding. They also liked that it could be a physical document for practitioners to refer to and revisit easily.

"the colour coding within the trajectory itself [was helpful]" (P8)

"I think having … pictures and having them different colours, has also made it just very, very visually pleasing, tool as well." (P13)

"[staff] like the fact they can come and have a look. It's a physical thing, they've got it there. They can look back on it." (P1)

A resource that is well organised, appealing, and easy-to-use is relevant in the context of practitioners having little time available for training and development, as highlighted in our theme 'limitations and barriers to implementation', described in the section below.

Utilisation of the multimodal resources within the SRT has been broad, with different elements preferred by different practitioners, depending on the specific needs of their setting or cohort:

“the posters were a really quick way in [to spatial reasoning] … it was good to kind of get people talking initially.” (P4)

“we often … watch video clips in our TA meetings and then I link them back to their Toolkits if I can and use examples from the website” (P2).

Again, this highlights the breadth of opportunities for application in early childhood education settings identified by the practitioners, as well as the flexibility in uses that they found in the resource.

Finally, within this theme, all the practitioners were enthusiastic about increasing resources in the Toolkit. Practitioner 7 suggested: *"a broader range of continuous provision posters, … maybe even like playtime sort of posters, which midday meal supervisors could use as prompts to support children with ... games"* (P7).

Theme 2: Suitable for curriculum integration. The Toolkit activities are suitable for integration into mathematics curriculum planning and have prompted curriculum development by practitioners. All practitioners stated that the resources had prompted them to reflect on their current teaching practice and identify how effectively spatial reasoning is addressed in their curriculum.

“*we've used [the SRT] to start looking at our curriculum, and where kind of the gaps are in spatial reasoning”* (P4)

“I am now on in the process of making sure spatial reasoning is progressive in the curriculum.” (P13)

"I embedded the spatial reasoning objectives out of the Toolkit into the medium term [curriculum] planning." (P1)

Practitioners actively using the materials have introduced activities from the Toolkit within their teaching and learning practice. Some practitioners felt that a recent shift of focus to number-related content in the primary KS1 (age 5 – 7 years) mathematics curriculum (DfE, 2017) may reduce emphasis on spatial reasoning activities that had previously been used in the classroom. This view is echoed in practitioner feedback on the revised ELG (EEF, 2019). One senior leader said,

"we've started having a discussion about our curriculum in our two primary schools, because we've focused so heavily on number and the mastering number program, we felt that spatial reasoning was maybe a little bit further behind in what we were doing." (P4)

Many of the practitioners highlighted how the Toolkit had supported them in incorporating spatial reasoning activities across the curriculum, not just in mathematics lessons. Activities in the SRT that encouraged children to work together, such as building large block models or completing obstacle courses, were helpful in meeting children's social development goals.

"we used it [the Toolkit] across the board in different lessons across the curriculum." (P10)

"[spatial reasoning] fitted well into lots of different lessons across the curriculum. Also, PSHE [Personal, social, health and economic education] ...working with your partner, working by yourself" (P11)

Theme 3: Limitations and barriers to implementation. There are some limitations to the Toolkit and barriers to implementation that potentially restrict its usefulness for practitioners.

Practitioners felt that a large investment of time is needed to review and digest the information in the SRT. This limits its use by members of staff who have reduced non-contact time available for training and development.

"What I would love is to send them [teachers] a link to the website and say this is great, use it, but it's probably, it's been like over 15 hours' worth of reading and getting my head around this" (P3)

In addition, trying to identify time for staff training is a particular pressure limiting the rollout of the Toolkit, especially when topics such as phonics and reading are prioritised in the Early Years curriculum over mathematics in many schools (Ofsted, 2017). As one practitioner commented: *"it's so hard to kind of find the time to do everything and phonics always get the priority"* (P6). Practitioners also talked about being frustrated at not being able to extend the uses of the SRT due to time and resource constraints. For example, an Early Years Lead expressed frustration at not having time to develop spatial-reasoning-related homework tasks: *"I know that I haven't reached ... parents with all the things I want to help them and support them with [in relation to spatial reasoning]."*

A few practitioners also felt the nature of some of the activity suggestions may limit the use to settings that incorporated continuous provision to a greater extent. One Key Stage 1 class teacher commented: *"I think depending on how your setting is organised as well, like we're not doing continuous provision in year two … we're very much doing you know, whole class maths, whole class English ... it would be really interesting to find out how we can do a little bit more in that sort of environment". (P12)*

A further aspect of this theme was some practitioners' feeling that despite the value of the Toolkit, other practitioners they were in contact with were not using it due to a lack of awareness. For example, a practitioner working in a multi academy trust highlighted that she was the only person in her trust who was aware of the launch of the toolkit.

Impact of the Toolkit

Theme 1: Empowering practitioners. The Toolkit has empowered practitioners to better support children's spatial reasoning. Practitioners consistently referred to how they, and the staff they worked with, could offer improved assistance following use of the SRT. The increase in understanding of spatial reasoning from a range of school staff (subject leader, teacher, teaching assistant, trainee teachers) and a resultant increase in enthusiasm for teaching spatial reasoning were recognised. A practitioner who had introduced large block play outdoors because of the Toolkit explained the impact for practitioners:

"I think the collaboration certainly in my class from September, to now with that large equipment outside and us as adults recognising the importance of it, and my team understanding; that has taken their [pupils'] play to a much deeper level, a much higher skill base than I think we would have done without that sort of understanding with the Toolkit."(P13)

The detailed content in the SRT, such as the development trajectories, has allowed practitioners to develop confidence in understanding what spatial reasoning is and in supporting spatial reasoning activities with the children in their settings.

"it's [the Toolkit] definitely given me more confidence. I don't feel I have come from a place where I have felt as confident delivering kind of number, spatial reasoning, shape, measure all those sorts of things within a class, as I have other areas of the early years' curriculum." (P7)

"A lot of our trainees have gone into settings where perhaps … there's still been a misunderstanding around the place of shape, space and measure … so being able to give them some really clear research-based guidance to come back to and really feel the importance of this as a part of the curriculum has been really helpful." (P8)

Theme 2: Positive impact on children's spatial reasoning. All the practitioners using the Toolkit reported that it has had a positive impact on children's spatial reasoning engagement and understanding. Examples of improvement included:

"hearing children now picking up on those questions that we asked ... and they're like, oh, well, what if we turn this, this way or what? What would happen if?" (P4),

"[an improvement to] language and using it in context and understanding what it means." (P1)

"children [are] less confused about how shapes [are] presented" (P6)

However, none of the practitioners in our study had formally tracked children's progression in spatial reasoning or considered how they would measure progress. A senior leader and mathematics lead highlighted a knowledge gap in this area: *"I wouldn't necessarily know what to do."* (P1). This suggests that investment is needed in the development of classroom-based assessment tools for spatial reasoning and supporting practitioners to implement them.

Theme 3: Facilitating child-led learning. The Toolkit is allowing children to have agency in their spatial reasoning learning. Many practitioners reported that children had particularly high levels of engagement when learning through the activities from the Toolkit. A Key Stage 1 class teacher shared her experience of a lesson making nets (2-D plans of 3-D shapes):

"there was a lot of independent … self-investigation, and the nets were one great example of that where they were really excited ... we started them off with the basics of the nets …but they wanted to investigate further" (P10).

Discussion among practitioners centered around how the activities facilitated physical manipulation and whole-body engagement i.e., *"they [pupils] have to move them [puzzles] around to create it … they just couldn't figure out how to do it and it was like 'stand up and move yourself around' and I think it gave them a different perspective on learning."* (P11).

Practitioners also talked about how children were empowered by the activities in the Toolkit to take control of their learning.

"it's [the Toolkit] allowing me to focus more on letting the children play with their agenda." (P3)

"They [children] got to take ownership of their learning in a way where it wasn't just us talking at them." (P10)

This child-led learning potentially extends the opportunities for children who are perceived to be lower attaining. For example, a practitioner commented that for children in her class who would typically find it more challenging to complete desk-based work, the activities from the Toolkit removed the barriers to progressing their own learning: *"when … they think it's more play, they carry on investigating"* (P11)

This further demonstrates the value participants placed on the Toolkit being particularly useful for practitioners working with children who are perceived to be lower attaining, such as those with special educational needs or from low socioeconomic households.

Discussion

Study 2 explored practitioner views of the usefulness and impact of the SRT on practice, the curriculum and children using qualitative methods. In line with Study 1, practitioners reported that the SRT had been used for a range of purposes by practitioners in different roles, highlighting the flexibility in application of the resources. Interestingly, practitioners also shared the flexibility of the SRT in supporting different groups of children – such as those deemed to be from disadvantaged backgrounds. The usefulness of the Toolkit in this context is especially important given the research evidence demonstrating that spatial reasoning interventions particularly benefit children from low socioeconomic backgrounds (Bower et al., 2020; Gilligan-Lee et al., 2023a; Schmitt et al., 2018). Practitioner interest in extending the use of the SRT for other pupil groups outside of the original intended age range of birth to seven years also demonstrates the flexibility of the materials and offers ideas for potential extension of the SRT's original purpose.

Creating accessible materials also appears to have influenced the use of the SRT. Presenting information in different formats facilitated the use by different types of practitioners and in different settings. This may have allowed for multi-layering of messages and reinforcement of key points contributing to the positive impacts reported. For example, watching a video in a staff meeting, curriculum planning integrating age-specific development steps from the trajectory and posters displayed in classrooms acting as prompts for 'in the moment' learning. Rycroft-Smith (2022) highlights delivering and curating content in appropriate formats, including suitable imagery and language as effective strategies for making resources accessible to education practitioners.

Curriculum integration of the development steps and associated activities demonstrates that the SRT is effective in supporting practitioners (outside of a research environment) to 'spatialise' the curriculum, a first step to enhancing children's mathematics skills. Participants adoption of, and enthusiasm for using spatial reasoning activities across different curriculum areas suggests that there could be more opportunities for enhancing children's spatial understanding than in just focusing on integration into mathematics lessons. However, care needs to be taken in how researchers guide practitioners in the most effective methods for integrating spatial activities if the main purpose is to develop children's mathematics understanding. Hawes et al. (2023) discuss both isolated (focus on single spatial skills with no relation to mathematics) and embedded (developing multiple spatial skills with links to the mathematics curriculum) approaches to incorporating spatial reasoning into the curriculum. Both approaches have been demonstrated to create transfer to mathematics understanding however neither is conclusive in consistently delivering these results. As research progresses it will be important to re-evaluate the guidance in the SRT to ensure it provides the most effective support for practitioners.

Despite responding to practitioners' feedback for actionable steps to support the identification of opportunities to incorporate spatial reasoning into the curriculum (Bates et al., 2023; Gripton et al., under review) the results in Study 2 show that digesting the information in the SRT is time consuming. Practitioners are time-poor (Drill et al., 2013) so further investment into distilling messages into digestible, time-efficient content such as shorter videos or cue cards may remove barriers to adoption of the SRT.

Regarding impact, Study 2 reinforces the findings of Study 1 that practitioner's understanding of spatial reasoning and confidence in supporting children's understanding increased due to using the SRT. This underlines the value of the Toolkit, particularly given other research findings that practitioners reported low confidence and a lack of knowledge in teaching spatial reasoning (Bates et al., 2023; Gilligan-Lee et al., 2023b). The positive impact of the SRT on children's spatial reasoning understanding was also a key theme, although formal assessment of spatial reasoning skills had not been undertaken by any participant. To our knowledge, no standardised measure of spatial reasoning currently exists for this age range. This presents a challenge to formally assess the progress of children's spatial reasoning. Finally, an additional benefit of the adoption of the SRT that practitioners highlighted was the increase in child-led activities. These activities offered social and communication development as well as spatial reasoning development. Critically, they also offered children perceived as lower ability the opportunity to be so deeply involved that they were in a state of 'flow' (Csikszentmihalyi, 2013) allowing them to progress their learning. Child-led play can also offer opportunities for practitioners to observe children's understanding of spatial reasoning and mathematics (Chilvers, 2021).

In summary, this project set out to establish how the SRT has been used by practitioners working with children from birth to 7 years and what impact it has generated. Study 1 and 2 were consistent in their findings; the SRT is a flexible tool that has been used by different types of practitioners, in different settings for a range of children for different purposes. The project is a good example of how to effectively translate research evidence into resources for practitioners to apply in their settings. Multi modal resources facilitated the accessibility of the resource and supported its flexible use. Time constraints appear to be the biggest barrier to users in adopting the SRT in practice. However, once practitioners had invested the time to digest the materials, they benefitted from an increase in confidence in explaining spatial reasoning to others. Significantly, practitioners perceived that children benefitted from an increase in understanding of spatial reasoning and mathematics.

Limitations

There were three main limitations with this research project. First, the participants were mainly drawn from school-based settings. Whilst the sample did include nursery and primary practitioners, the project did not manage to engage many adults working with children from birth to four years in settings such as private nurseries or at home. To fully understand the usefulness and impact of the SRT across the target age-range, future research should focus on non-school based practitioners working with the birth-to-three-years age group. It would also be valuable to conduct controlled intervention studies to understand the causal relationships between use of the SRT and the impacts. Second, the participation level in Study 1 was underpowered. A priori power analysis, using G*Power (Faul et al., 2007) indicated that a sample size of 53 in each group was required for a power of .80 with an alpha of .05. Third, whilst effort was invested in including practitioners who had not used the SRT in the research to minimise participant bias (Keeble et al., 2013), the recruitment methods used meant that we likely engaged those early adopters and enthusiastic champions of the resource. Therefore, caution needs to be applied in extrapolating the positivity of the findings across the early years education sector.

Implications for practice

This project demonstrates that the SRT can offer support to those working with young children to develop their spatial reasoning skills. Given time to digest the materials and plan how to incorporate the SRT into a particular setting, practitioners can create impact for their own development, the curriculum and children's understanding of spatial reasoning and mathematics.

This provides a starting point for practitioners looking for strategies to support greater development of young children's mathematics skills. To maximise the impact for children in England, further work needs to be undertaken to communicate the benefits of the SRT to educators. Future research regarding these resources should seek to engage practitioners working with children from birth to three years to broaden the understanding of the use and impact of the SRT.

Additionally, for researchers seeking to support education practitioners to effectively implement evidence-based strategies the SRT provides a model. Resources designed in consultation with practitioners that offer multi-modal materials, age-specific development steps and are easily accessible can create impact.

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