International Journal of Early Childhood
https://doi.org/10.1007/s13158-022-00317-y

ORIGINAL RESEARCH

Spatial Skills Among Young Children in Morogoro, Tanzania: Examining the Effectiveness of a School-Based Intervention

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Accepted: 16 January 2022

Abstract
Along with emerging literacy and numeracy, spatial skills and reasoning set the foundation for young children's school readiness and early education. This study explored introducing an innovative curriculum for promoting young children's spatial learning in Morogoro, Tanzania. Four hundred twenty-eight children from 21 schools participated; 11 schools received a seven-week educational intervention using Pattern ABC cards, while another 10 schools served as a control group. Within the intervention schools, six received a "boost" training to assist in delivering the intervention lessons. At baseline, children demonstrated low levels of literacy, numeracy, and spatial skills. The team estimated multivariate hierarchical linear models after the intervention and found that those children in classrooms with the boost performed significantly better than those in the regular intervention and control classrooms on several core spatial skills, including identification, naming, and matching to line drawings. This study offers evidence that an educational intervention featuring shapes and patterns can be delivered although it was a challenge, as it differs greatly from the typical pedagogical approach in this low-income, resource-poor environment. Greater teacher training can increase the program effects, particularly with respect to successful implementation of lessons involving less frequently taught spatial concepts and approaches.

Keywords Early childhood education · Shapes · Spatial · Preschoolers · Africa · Education

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Published online: 26 February 2022

Background

In their fifty years of cumulative research, Wai et al. (2009) advance that spatial ability is of equal (and differential) importance to literacy and mathematics in successful academic and work world pursuits. This is especially true with respect to STEM-related (science, technology, engineering, and mathematics) fields. Researchers report, for example, that children's spatial skill at age five years predicts their performance on symbolic calculation tasks at age 8 (Gunderson et al., 2012). Yet despite rich data from a range of research, including longitudinal designs, there remains a "contemporary neglect [by educators] of utilizing psychological knowledge about spatial ability" (p. 817). This inattention is particularly significant given the growing importance of STEM-related knowledge in the modern world, in general, and in the workforce, specifically.

From preschool to post-graduate schooling, educators often gauge academic achievement with mathematical and verbal measures. Most partition spatial reasoning to a limited aspect of mathematics and/or ancillary art curricula. Spatial reasoning is defined as "the ability to

generate, retain, retrieve, and transform well-structured visual images" (Lohman, 1994, p. 1000). "Spatial skills" refers to a variety of related abilities, including manipulation of objects mentally and within occupied space (Uttal et al., 2013). Many intellectually-talented students show strong spatial abilities that are distinct from literacy and math achievement. These abilities are separately associated with diverse educational domains, including science, technology, engineering, and mathematics (Wai et al., 2009). Research with British primary school children showed that intrinsic and extrinsic spatial skills (both static and dynamic) predicted the children's later science achievement (Hodgkiss et al., 2018).

Longitudinal findings also reveal that spatial aptitude predicts involvement in STEM careers (Wai et al., 2009, 2010).

Researchers have shown the benefits of teaching spatial skills (Battista, 1999; Gilligan et al., 2019; Uttal et al., 2013). Children who receive explicit and implicit spatial instruction can express near, immediate, and far transfer of skills (Gilligan et al., 2019). Others have shown that developing spatial skills can improve young children's school readiness (Verdine et al., 2014). Improved spatial skills may facilitate and advance traditional skills taught in early elementary grades, like letter and number learning, geometric reasoning, and multiplicative thinking (Battista, 1999). These skills go beyond standard ("canonical") shapes more typically taught to young children (e.g., circles, squares, and triangles) and can include sophisticated geometric shapes (what some researchers call "non-canonical" forms) (Verdine et al., 2019).

Given the potential benefits, there is a need and value in introducing a richer array of spatial reasoning lessons, beyond what is currently available in school and home settings. Innovative curricula, especially in low- and middle-income countries (LMICs) locations, that focus on spatial skills might give children an inventive boost to their education. Such an approach might draw out abilities that children in such environments might already possess. What is observed in conventional classrooms may not be a true picture of children's skills and potential. Philosopher and educator Paulo Friere discuss in his 1970 book *Pedagogy of the Oppressed* that traditional pedagogy may inaccurately assess children's contextual and community-based skills and knowledge, especially among those living in underprivileged environments (Freire, 1970). Similarly, Nunes and colleagues (1993) revealed that Brazilian children working on the streets of Recife could successfully perform complex mathematical calculations in their heads. However, when presented with the same problems using typical school word problems, the children were less able to do the computations. Especially in challenging locations, it is possible that children can better learn and apply concepts when they are presented in more culturally- and setting-specific ways. Existing and developing spatial aptitudes may serve vulnerable children as foundational, useful, and marketable, in a way that more rigid systems fail such children.

This study is the first formal attempt to examine a school-based intervention using the Pattern ABC system in a low-income country. The Pattern ABC system consists of 32 basic growth patterns and shapes that serve as building blocks of visual understanding, in the way the letters of the alphabet are fundamental to literacy learning. The creators of this system wanted to see if and how exposure to the Pattern ABC system could promote learning not just of patterns and shapes but also if this system might result in improving other school-based and educational skills.

The Pattern ABC system involves a set of cards, with each card depicting a different pattern (on one side) (see Figure 1) and listing activities (on the other side) to understand and experience formations in different ways (iD, 2D, 3D, and 4D). These ways include:

- iD (identification) activities are designed to build children's observation and imagination. They challenge children to find patterns in the world and to remember things they have seen.
- 2D activities refer to "flatwork" such as sketching and collage on paper, drawing in the sand or the dirt with a stick, and "dis-embedding" - finding images within drawings or photographs.
- 3D activities involve making objects from materials, including art supplies or found objects.
- 4D activities engage children in movement. These activities don't require supplies, just children. The activities work best with small groups, ranging from one child making shapes with their body to a few children making shapes together.

To obtain additional information about the Pattern ABC system, please refer to the website https://www.na2ure.com/.

It was anticipated that the Pattern ABC system could teach young children to recognize patterns and build a foundational understanding of spatial relations in the real world. Furthermore, gaining spatial ability through this approach might promote learning in other educational domains. The simplicity of the Pattern ABC system and its potential value to build skills bolstering children's STEM competencies has appeal for distribution in low-resource settings, where ease of use and low expense are requisites of successful educational curricula and materials.

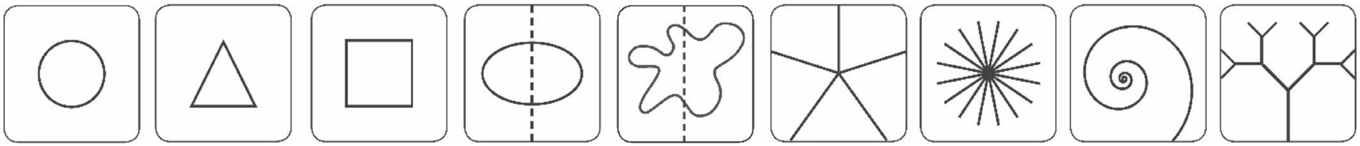

Fig. 1 Examples of Pattern ABC cards: Circle, Triangle, Square, Bilateral Symmetry, Asymmetry, 5 shapes, Explosion, Spiral, and Branching

The Pattern ABC system creators have successfully worked with parents and teachers in the United States, showing them how to encourage spatial activities and learning among preschool-aged children (Wolf, 2018). This work described in this paper uses a more scientific approach and in a very different setting. In contrast to just trying out the system informally and resource-rich locations, the study sets out to explore the effect and use of the Pattern ABC system with children who have access to relatively few resources and practically no educational materials beyond slates and notebooks. Our research team typically works in and is very familiar with rural Tanzania, where electricity and indoor plumbing rare. Schools have few supplies and educational material; classrooms are crowded, with children crammed on benches and a single teacher in front of a chalkboard. It is easy to bring the Pattern ABC system to such locations, as it does not require unobtainable supplies.

While available to Tanzanian children ages 5 to 6 years, pre-primary education is not mandatory, and parents can opt-out of sending their children to school. In sub-Saharan Africa, many parents regard pre-primary education as preparation for primary school, where there is great emphasis on traditional academic skills. As Marfo and Biersteker (2011) describe, African children often encounter old-fashioned, institutionalized, and strict Western-style schooling, that does not integrate local contexts, realities, and assets. Across the English-speaking world, early childhood education now embraces the “pedagogy of play” (Brooker, 2011). In contrast, since the era of colonization, African parents and teachers see ECE programs as the place for young children to gain academic and cognitive competencies over more holistic development. Furthermore, in most parts of the non-Western world, few recognize the importance of spatial reasoning skills (Mtahabwa & Rao, 2010). In Tanzania, lessons focus on traditional rote learning delivered through didactic approaches, rather than the more holistic playful approaches commonly advocated for young children in other parts of the world (Zosh et al., 2017). Additionally, many external challenges, including extreme teacher/pupil ratios (around 1:50 in urban and 1:90 in rural settings), bare and small physical settings for learning, an orientation toward product rather than process education, and untrained or partially-trained teachers further inhibit student achievement (Mtahabwa & Rao, 2010).

Typically, first-rate pre-primary education is rare in this region of the world. Burchinal (2018) defines quality early education as involving sensitive and responsive interactions as well as intentional teaching of age-appropriate skills and scaffolding of learning. When Aboud and colleagues (2017) evaluated pre-primary programs in East Africa, they found few instances of positive interactions between the teacher and children, mostly teacher-led instruction with little play (indoor or outdoor), repetition of teachers’ oral recitation of letters and words, and a lack of object manipulation in teaching of numeracy.

The Pattern ABC curriculum would differ from what is often found in most rural East African ECE schools and programs. However, the potential of this curriculum is that it could introduce a new and innovative type of instruction at little cost, using local context and material. From this study, we could examine not only if young children could learn new material but also if it would be accepted and successfully implemented.

Only a handful of published studies examine the effectiveness of early childhood curricular interventions in sub-Saharan Africa in general and Tanzania specifically. Of the research conducted in this region, researchers tend to focus on infrastructure that can affect children's learning. For example, Mtahabwa and Rao (2010) found linkages between Tanzanian teacher's training and the quality of classroom experiences. Mligo (2018), who studied impediments to implementation and economic factors, suggested that quality early childhood education will only happen in Tanzania when early childhood is prioritized by the government. While some raise concerns about the rigid, didactic teaching styles typically used in sub-Saharan classrooms (Boger et al., 2013; Pitsoe & Maila, 2012), we are aware of very few tested educational interventions that employ constructivist and manipulative approaches. Another benefit of testing the Pattern ABC curriculum is that it contributes to the limited literature on innovative ECE programs in this region.

The published literature lacks data on the interrelationship of early educational skills among young children, from Tanzania and other parts of sub-Saharan Africa. While there is work from middle- and high-income countries (including Finland, Malaysia, and the U.S.) showing relations between children's literacy, numeracy, and spatial awareness abilities (Musliman et al., 2013; Wai et al., 2009; Zhang et al., 2014), no similar work that we are aware of comes from the African continent. When researchers evaluate educational curricula, they often use imported instruments with little or few modifications (Mwaura & Marfo, 2011); this study of the Pattern ABC curriculum involved adapting measures so they were more culturally appropriate. We provide data on rural Tanzanian children, showing strengths and weaknesses in pre-primary and school-readiness skills.

This study had three goals. The first was to examine the effect of an intervention, using the Pattern ABC cards within ECE programs, to see if it was possible to improve spatial skills among children living in low-income, poor-resource communities (in this case, Morogoro, Tanzania). This was the first formal, naturalistic, and scientific testing of these intervention materials, where vulnerable children might learn about shapes and how they appear in our daily lives and environments. This study, however, offers much more. In doing this intervention, we examined whether a novel teaching approach would be accepted by East African teachers who typically use rigid and didactic approaches. Could teachers be trained to successfully deliver more constructivist-based lesson plans? Finally, this study contributes to the literature on early childhood education and learning. We studied African children from rural Tanzania, a sample that is not often examined. We prepared instruments, collected data, and were able to investigate the relations among Tanzanian children's literacy, numeracy, and spatial skills. Respectively, the team considered the following three questions:

1. Can and how much do young rural Tanzanian children learn spatial skills from participating in an educational intervention that utilizes the Pattern ABC cards and activities?
2. Can an educational intervention that utilizes novel and playful activities be effectively deployed by teachers in a low-resource school setting in Tanzania?

3. Among young rural Tanzania children, what are the relations between children's literacy, numeracy, and spatial skills?

Methods

Study Setting and Recruitment

The research protocols and instruments received approval from the Tanzanian Commission for Science and Technology (COSTECH) and the University of Maryland's Institutional Review Board.

The study took place in Spring 2019 in Morogoro, Tanzania (see Fig. 2). With a population of approximately 2.7 millioin people (National Bureau of Statistics 2022), Morogoro is in the eastern part of Tanzania at the base of the Uluguru Mountains. Morogoro is mostly rural, and the livelihood of the population is mainly gained from agriculture and natural resources. People in this region do not have consistent access to electricity, improved sanitation, and safe water.

The study occurred in government schools with the schools' youngest children: those in the ECE programs. It should be noted that these classrooms typically are "catchall classrooms," with youngsters of diverse ages and abilities. In rural parts of Tanzania, some parents wait until their children are old enough to walk independently the kilometers to and from school. In some cases, younger siblings tag along, and they too are part of this early classroom.

The research team reached out to school principals and headmasters in 21 public schools that housed ECE programs and classes; all contacted schools agreed to participate. In every one of these schools, the ECE program involved a single classroom of children with just one teacher. While the languages of instruction in the schools were Kiswahili and English, this study and intervention were done in Kiswahili.

Prior to implementation, the research team discussed the project with the school administrators, indicating that the project would involve randomized assignment of control and treatment schools. Researchers provided basic information about the study, stating that it would be examining an innovative school curriculum where shapes and patterns would be introduced but did not provide any detail about the specifics of the educational messages or pedagogic approach. The researchers explained that all schools would receive art supplies and materials, but only teachers in the treatment schools would implement the new curriculum. There were no costs to the schools to be involved in the study.

The protocol required active parental consent and active participant assent. The schools sent home consent forms or hand-delivered them to parents (and orally explained when necessary) to all those in the school's ECE program. The selected schools had between 20 and 65 children attending their ECE program, which was in every situation, housed in just one classroom. From among those children who returned parental consent forms, researchers randomly selected 20 to 25 children from each school to participate.

Through one-on-one interviewers, researchers collected data from all participating children at baseline and immediately following a seven-week intervention.

Fig. 2 Location map and photograph of Morogoro, Tanzania (Photo credit Mussa Chale)

The total baseline sample consisted of 429 children. Of these, 30 dropped out of the intervention, leaving 399 children who participated in both the baseline and post-intervention data collection. We observed no significant demographic differences between those who left and remained in the study.

The Intervention

Development of the intervention involved discussions among those who created the Pattern ABC cards, spatial skills experts, developmental psychologists, and members of the Tanzanian community. We worked with 2 ECE teachers around 40 km outside of Dar es Salaam, who helped shape the lessons.

Works of several developmental and educational psychologists contributed to the intervention design. For example, the team used Bandura's social cognitive theory and recommended that teachers instruct through modeling and positive reinforcement (Bandura, 1986). In most of the lessons, the teacher asked children to imitate what she and the other children were doing. Bruner's work contributed to the intervention design, where the curriculum frequently asked children to be engaged both physically and with their environments to learn new concepts (Bruner, 1990). Children constructed the new patterns and shapes with found materials and their bodies. Vygotsky's sociocultural theory and ideas of scaffolding were used not just for the child learners, but also for the teachers attempting to try new styles of instruction (Vygotsky, 1978).

Besides applying the philosophies of Western scholars, this intervention tried to incorporate recommendations of African thinkers. Similar to suggestions made by Mwaura and Marfo (2011) in their description of the Madrasa Resource Centers in East Africa, this intervention involved active learning with local and familiar materials. Advisors from the region were in favor of children being agents immersed in their socio-cultural milieu, manipulating and discovering the educational content with provincial tools and items. In agreement, team members and teachers agreed and planned for a constructivist approach in this intervention, allowing engagement beyond the traditional recitation and memorization often characteristic in these classrooms.

The intervention involved treatment teachers delivering daily 20 min lessons on nine of the different shapes/patterns featured in the Pattern ABC cards. These nine represented three easier, medium, and harder shapes/patterns. Students would participate in exercises that sequentially introduced iD, 2D, 3D, and 4D approaches for each shape/pattern (see Fig. 3). The nine shapes/patterns of this intervention included: circle, triangle, square, bilateral symmetry, 5 shapes, asymmetry, spiral, branching, and explosion. The iD approach conceptualized or described a specific shape or pattern, identifying it in the real world. 2D involved "flat" work where children sketched or made collage shapes/ patterns on paper. With 3D, children made shapes/patterns using classroom materials and found objects. 4D exercises had children engage in movement activities using gross motor skills; children formed the shape/pattern with their own bodies.

Fig. 3 Children's work and engagement in 2D (left), 3D (middle), and 4D (right) exercises (Photo credit Mussa Chale)

Each shape/pattern lesson spanned three days. Every day, the teacher would start the lesson using the iD approach, where children would identify the shape/pattern in both indoor and outdoor spaces. This served as an introduction (or reminder) of the new shape/pattern. On the first of the three days, after discussing the new shape/pattern (iD approach), the teacher would have students do 2D activities drawing and outlining the shape/pattern on flat surfaces. The second day would include 3D activities where the children would make the shape/pattern with supplied and found materials. On the third day, children participated in 4D activities where children made the shapes/patterns with their own bodies.

Critical to this project, an intervention team worked extensively before and during the study with the teachers who would deliver the curriculum. Teachers received a notebook with laminated shapes and patterns, as well as images and suggested activities. A two-day in-person training occurred prior to the intervention, where the study's six-person intervention team went through every shape and practiced lessons with the participating teachers. There were discussions about the constructionist approach and teachers enthusiastically agreed to try this style of teaching during the intervention.

Addressing the fidelity of the intervention, team members monitored the lessons, visiting schools and observing lessons every three to four days. In these visits, team members collected qualitative data. They discussed with the teachers the lesson delivery and teachers' perceptions of how things were going. Teachers told the team members what shape/pattern they were teaching, the time and effort spent in delivering the lessons, and whether they felt the students enjoyed and understood the presented material.

During the intervention, team members were available to help with the lessons. In six of the eleven intervention schools, teachers asked for a "boost." The boosts varied by school. In three of the six boost schools, the team member spent more time only with the teacher, reviewing the lesson plans and offering additional examples and ideas of activities. In two boost schools, the team member helped in delivering the lesson and activities, serving as a classroom assistant. In the final boost school, the teacher had the intervention team member act as the primary instructor, who then delivered two of the shape/pattern lessons and activities.

Research Protocols and Measures

Protocols

The team that designed the intervention also reviewed the research protocols and instruments. A Tanzanian team worked with 40 preschool children around 40 km outside of Dar es Salaam to pilot test the intervention and protocols for the study. This was done to assess the perceived feasibility and ensure that the protocols were culturally- and age-appropriate. For the measures, many questions came from the Save the Children International Development and Early Learning Assessment (IDELA) tool which is widely used in low and middle-income countries LMICs (Pisani et al., 2015). Other questions were developed specifically for this research study. Several instruments included photographs that research team members took in Tanzanian settings to ensure that items were recognizable. There were substantial efforts made to have measures that were both reliable and locally produced.

Twelve Tanzanian researchers underwent extensive training with the lead researchers and the in-country project manager. There was in-person supervision as well so that protocols were delivered in an ethical, reliable, and valid manner.

The trained data collectors conducted interviews one-on-one with each child, in Kiswahili or in the child's preferred dialect. Surveys occurred at the children's schools, at baseline, and again nine weeks later. The interviews took, on average, 30 min. Because children in this developmental stage are often reticent around new people, the survey's questions allowed children to point to images, match picture cards, or provide one-word answers.

It was not until after the team completed the baseline surveys with the children that the schools were randomly assigned to either the treatment or the control group. Then, the team trained the intervention teachers, to avoid potential contamination of the children's baseline data. As previously mentioned, teachers at the eleven treatment schools received intervention materials as well as art supplies; the remaining teachers at the ten control schools only received the art supplies.

Measures

Shape/pattern Items

To assess shape/pattern identification and naming, the researcher showed the participating child a three-by-three grid, with a shape/pattern in each cell. First, the researcher named shapes/patterns, and asked the child to point to each on the grid (shape identification, Cronbach's alpha = 0.53). Next, the researcher pointed to cells on a new grid and asked the child to name nine shapes/patterns (shape naming, Cronbach's alpha = 0.58).

Next, the researcher showed the child a card with one of the nine shapes/patterns at the top and then asked the child to choose the most similar shape/pattern from among four line drawings below. This process was repeated for all nine shapes/patterns. This line drawing matching assessment had a Cronbach's alpha of 0.41.

The next set of questions assessed the child's unaided and aided identification of shapes/patterns in the real world. For the unaided real-world shape/pattern, the researcher showed the child four images from the real world. The researcher instructed the child to "*Please point to the picture that shows a [shape name] in the real world. A [shape name].*" The Cronbach's alpha for unaided real-world shape identification was quite low (0.32), indicating very low internal consistency among the nine shapes/patterns tested.

With the aided real-world shapes/patterns, researchers showed children a page with a line drawing of a single shape/pattern and four photographs. Here, researchers pointed to the line drawing and said, *"This is a picture of a [shape name]. Please point to the picture that shows a [shape name] in the real world. A [shape name]."* The Cronbach's alpha for aided real-world shape was 0.53.

Literacy and Numeracy Measures

In this study, we included several measures from the widely-used IDELA instrument, in order to reliably capture school-readiness constructs. The team assessed fundamental literacy by measuring children's letter identification and naming skills. Researchers showed children two separate picture cards of 16 letters, randomly placed in a four-by-four grid. Holding the first picture card, the researcher named, one at a time, eight letters and asked the child to point to the letter in the grid (letter identification, Cronbach's alpha = 0.84). Using a second picture card, also a grid of 16 letters, the researcher pointed to eight letters, one at a time, and asked the child to name the letter (letter naming, Cronbach's alpha = 0.88).

The team examined numeracy similarly. Holding a picture card with a four-by-four grid of 16 numbers between 1 and 20, the researcher asked the child to point to eight different numbers (number identification, Cronbach's alpha = 0.84). On a second picture card, also with a grid of 16 numbers, the researcher pointed to eight numbers. One at a time, the child named the number to which the researcher pointed (number naming, Cronbach's alpha = 0.89).

Other Measures

The instruments also tested children's ability in size ordering using an adaptation of the IDELA instrument. For this measure, researchers handed children three cards, each showing a small, medium, or large cat. The researcher asked the child to place the images in order from smallest to largest, indicating that the smallest cat should be placed on the left and the largest on the right. This procedure was repeated with images of small, medium, and large shirts. With just two items, we found a correlation between the measures of medium strength ($r = 0.46$).

The final assessed skill was name writing (which is also used in the IDELA instrument). Interviewers asked children "Can you show me how you write your name? Don't worry if you can't do it well; just try your best." Scoring was based on presence and clarity of letter-like forms, ranging from 0 (the child wrote nothing) to 4 (the child wrote his or her name clearly).

Comments on Internal Consistency

Four items (letter and number identification and naming) showed high internal consistency, as measured through the Cronbach's alpha. In contrast, the shape/pattern scales (shape naming, shape identification, and shape line drawing) had lower Cronbach's alphas, suggesting low internal consistency. As previously mentioned, one objective of this research was see if we could successfully conduct this type of work in a low-resource environment. As a result, we created or adapted several instruments for this study, as none previously existed for this population. We feel that researchers should continue to explore how to best measure these constructs, especially given the low Cronbach's alphas. We believe that shape/pattern learning is more variable and less unified than literacy and numeracy learning, and could result in such inconsistencies. While there are existing curricula for teaching letters and numbers, shape/pattern learning, particularly in terms of the non-canonical shapes, is less standardized. Possibly, the relatively low alphas speak more to the inconsistency in individual exposure than conceptual understanding of shapes/patterns.

Analyses

The quantitative analyses were done using STATA 16. We performed a factor analysis; however, no obvious or logical groupings of the various outcomes emerged. Besides considering univariate and bivariate relationships, the study team used hierarchical linear models (HLM) to examine what predicted children's post-intervention scores. HLM was used to account for potential interdependence of children's skills within schools. Our models also controlled for the child's sex, age, and baseline score.

The qualitative analyses involved thematic review of 82 memos, written and translated by team members during their in-person visits. These memos varied in length (several keywords to several pages) offering insight from the teacher and observer on what worked well and failed during the intervention.

Results

Table 1 presents descriptive data on the sample. On average, the studied children were 4.7 years old in the control schools and slightly older, 4.9 years, in the intervention schools (Student $t = 2.2$, $p < 0.05$). There were no significant differences with respect to child's sex for the two groups.

Baseline and post-intervention measures appear in Table 2. Overall, children had low levels of skill attainment in all the tested areas, with a significant difference between control and intervention schools for only the literacy items. At baseline, most children performed near the bottom of the scales, getting only a few answers correct. For example, out of eight naming number questions, children got an average

Table 1 Demographics of the participating children at baseline (N = 429)

	Overall 21 schools 429 children N (%)	Control 10 schools 207 children N (%)	Intervention 11 schools 222 children N (%)
Gender			
Girls	226 (52.7)	103 (49.8)	123 (55.4)
Boys	203 (47.3)	104 (50.2)	99 (44.6)
Age			
3 years	28 (6.5)	21 (10.1)	7 (3.2)
4 years	118 (27.5)	54 (26.1)	64 (28.8)
5 years	202 (47.1)	99 (47.8)	104 (46.8)
6 years	81 (18.9)	33 (15.9)	49 (22.1)

Table 2 Baseline and post-intervention scores for each construct

	Baseline				Post-Intervention			
	Overall (N = 429) Mean (SD)	Control (N = 207) Mean (SD)	Intervention (N = 222) Mean (SD)	Student *t*-test	Overall (N = 396) Mean (SD)	Control (N = 191) Mean (SD)	Intervention (N = 205) Mean (SD)	Student *t*-test
Spatial Skills								
Identifying shapes	1.77 (1.48)	1.79 (1.54)	1.76 (1.43)	NS	2.26 (1.81)	1.86 (1.57)	2.63 (1.95)	−4.4***
Naming shapes	1.27 (1.26)	1.22 (1.26)	1.32 (1.26)	NS	1.98 (1.70)	1.61 (1.46)	2.33 (1.83)	−4.3***
Matching to line drawings	4.67 (1.60)	4.70 (1.64)	4.64 (1.56)	NS	4.89 (1.49)	4.68 (1.46)	5.08 (1.49)	−2.7**
Unaided real world shapes	3.18 (1.49)	3.28 (1.50)	3.08 (1.48)	NS	4.09 (2.23)	4.02 (2.13)	4.16 (2.32)	NS
Aided real-world shapes	4.49 (2.07)	4.61 (2.01)	4.38 (2.13)	NS	4.45 (2.29)	4.34 (2.17)	4.54 (2.38)	NS
Literacy								
Identifying letters	1.10 (1.87)	1.36 (2.15)	0.86 (1.53)	2.7**	1.68 (2.26)	1.93 (2.49)	1.45 (1.99)	2.1*
Naming letters	1.30 (2.08)	1.52 (2.34)	1.09 (1.78)	2.1*	1.71 (2.44)	2.14 (2.79)	1.30 (2.00)	3.4***
Numeracy								
Identifying numbers	2.49 (2.51)	2.57 (2.58)	2.41 (2.45)	NS	3.61 (2.55)	3.46 (2.48)	3.75 (2.61)	NS
Naming numbers	2.85 (2.71)	2.41 (2.71)	2.76 (2.72)	NS	3.21 (2.68)	2.92 (2.59)	3.47 (2.755)	-2.1*
Other Skills								
Size ordering	0.18 (0.46)	0.20 (0.48)	0.16 (0.44)	NS	0.23 (0.57)	0.23 (0.57)	0.24 (0.57)	NS
Name writing	2.58 (1.01)	2.61 (1.01)	2.55 (1.01)	NS	2.82 (0.88)	2.90 (0.85)	2.75 (0.90)	NS

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$

of 2.85 correct. Of nine items for identifying shapes, children on average got 1.77 correct. There were 10 items for unaided real-world shapes; on average, children got 3.18 items correct at baseline. Performance was slightly better for aided real-world shapes: out of 10 items, children got 4.49 items correct. The poorest performance was for size ordering; the average baseline score was 0.18. Only 9.6% of the children were able to correctly place three cards depicting different-sized shirts in order from smallest to largest, and 8.3% correctly ordered three picture cards of cats.

Figure 4 displays how mean scores for most measures improved from baseline to post for both the intervention and the control groups.

In Table 3, we provide the Pearson correlations showing the relationships between the different constructs after the intervention. Practically all the correlations were positive, moderate, and significant at both baseline and post. This table offers evidence that children's spatial abilities were associated with a range of school-readiness skills.

Table 4 shows the first set of HLM multivariate analyses models. Nesting was at the school level (there was only one ECE classroom in each of these schools), these models explore whether being in the intervention predicted the outcomes over and above the effects of a child's sex, age, and baseline score. Among the covariates, sex was a significant predictor for only letter identification (with females scoring slightly higher than males). Age was a predictor in eight of the eleven models. Baseline score significantly predicted post-intervention scores, in all but the size-ordering model.

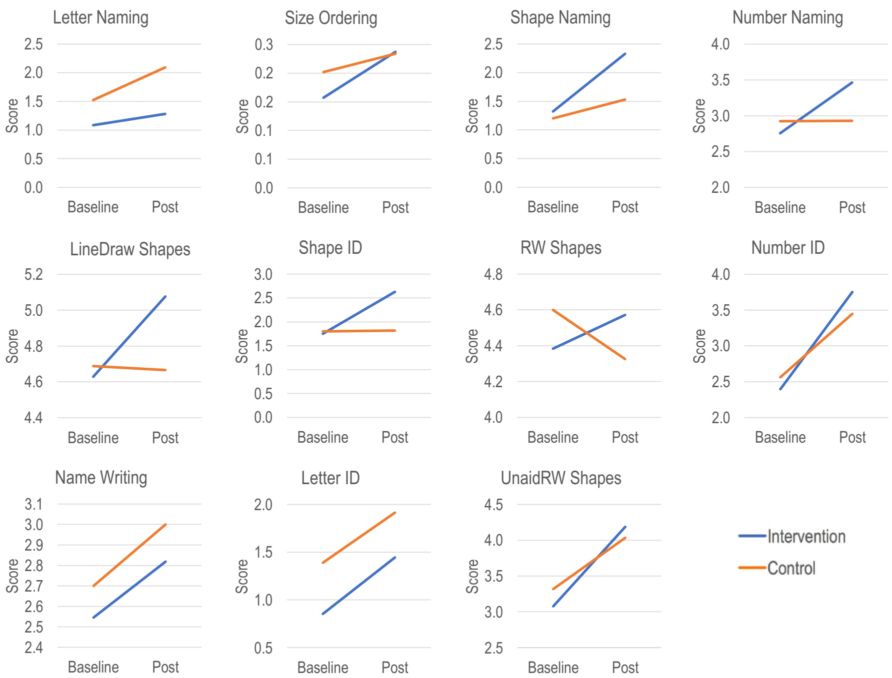

Fig. 4 Changes in mean scores from baseline to post-intervention

Table 3 Pearson correlations among the outcome items (n = 399)

	1	2	3	4	5	6	7	8	9	10
1) Shape identification										
2) Shape naming	0.73^{***}									
3) Matching shapes to line drawing	0.35^{***}	0.38^{***}								
4) Unaided real-world shapes	0.45^{***}	0.43^{***}	0.30^{***}							
5) Aided real-world shapes	0.49^{***}	0.46^{***}	0.39^{***}	0.65^{***}						
6) Letter identification	0.27^{***}	0.27^{***}	0.23^{***}	0.30^{***}	0.31^{***}					
7) Letter naming	0.22^{***}	0.24^{***}	0.22^{***}	0.29^{***}	0.28^{***}	0.82^{***}				
8) Number identification	0.44^{***}	0.41^{***}	0.28^{***}	0.44^{***}	0.42^{***}	0.54^{***}	0.51^{***}			
9) Number naming	0.42^{***}	0.37^{***}	0.29^{***}	0.40^{***}	0.44^{***}	0.59^{***}	0.54^{***}	0.83^{***}		
10) Size ordering	0.18^{**}	0.13^{***}	0.12^{***}	0.26^{***}	0.29^{***}	0.22^{***}	0.21^{***}	0.18^{***}	0.19^{***}	
11) Name writing	0.21^{***}	0.19^{***}	0.11^{*}	0.16^{***}	0.26^{***}	0.45^{***}	0.44^{***}	0.46^{***}	0.43^{***}	0.23^{***}

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 4 HLM multivariate models predicting outcome constructs

Outcome constructs	Gender (ref = Male) Coefficient (p value)	Age coefficient (p value)	Baseline score coefficient (p value)	Condition (ref = Control) Coefficient (p value)
Shape identification	0.23 (0.10)	**0.34 (< 0.01)**	**0.28 (< 0.01)**	**0.79 (0.01)**
Shape naming	0.09 (0.45)	**0.39 (< 0.01)**	**0.42 (< 0.01)**	**0.70 (0.01)**
Matching shapes to line drawings	0.08 (0.52)	**0.34 (< 0.01)**	**0.13 (< 0.01)**	**0.39 (0.07)**
Unaided real-world shapes	0.24 (0.24)	**0.69 (< 0.01)**	**0.15 (0.04)**	0.07 (0.81)
Aided real-world shapes	0.14 (0.49)	**0.46 (< 0.01)**	**0.29 (< 0.01)**	0.24 (0.42)
Letter identification	**0.35 (0.01)**	− 0.01 (0.95)	**0.70 (< 0.01)**	− 0.13 (0.67)
Letter naming	0.21 (0.12)	− 0.01 (0.86)	**0.78 (< 0.01)**	**− 0.49 (0.07)**
Number identification	0.16 (0.33)	**0.45 (< 0.01)**	**0.58 (< 0.01)**	0.33 (0.33)
Number naming	0.14 (0.37)	**0.36 (< 0.01)**	**0.64 (< 0.01)**	**0.62 (0.06)**
Size ordering	− 0.00 (0.99)	**0.07 (0.04)**	0.05 (0.44)	− 0.00 (0.98)
Name writing	0.11 (0.09)	0.06 (0.20)	**0.37 (< 0.01)**	− 0.14 (0.24)

The provided coefficients are standardized

Bolded numbers represent coefficients that are significant at a $p < 0.10$ level

Being in the intervention schools significantly predicted improved performance on the outcome construct for shape identification, shape naming, matching shapes to line drawing, and number naming. Being in the intervention predicted a lower score on the outcome construct of letter naming. Being in the intervention did not predict higher scores for the aided and unaided real-world shape constructs.

The analyses exploring whether having the boost (that is, a member of the intervention team providing extra assistance to the teacher) revealed the findings offered in Table 5. In these models, we compared the two intervention groups (those who used the boost versus those who did the standard intervention with no boost) to a reference group of those in the control schools. Those in the intervention schools with no boost did not perform better than those in the control schools; in contrast, children in schools with a boost performed significantly better in identification, shape naming, and shape line drawing than those in the control schools.

Qualitative Findings

The intervention trained and worked with eleven teachers to deliver the Pattern ABC curricula. All the teachers were women, with an average age of 34.7 years. There were no new teachers; all but two had greater than five years of experience teaching and most had worked with the youngest students for their careers. None had formal training in early childhood education.

During and immediately after the in-person training, the teachers expressed excitement about using the curriculum with their students. They said they had confident that they could deliver the lessons; although this was a new approach, the teachers were prepared and willing to try something new. The teachers appreciated the materials and believed that their students would enjoy the lessons.

Team members observed teachers devoting around 25 min a day to the shape/pattern lesson. Each day, the teacher would describe the new shape/pattern, typically standing in front of the classroom and drawing the shape/pattern on a chalkboard. Of the eleven teachers, five left the classroom and did the exercises outside; some went on walks near the school and others had the children explore and then return to circles to practice drawing in the sand or using stones to form the shape/patterns. The remaining six intervention teachers did not deviate much from the ways they presented and taught other topics. In these classrooms, children sat stiffly on wooden benches and worked mostly on slates. Even when the 4D lessons occurred, the teacher would bring a boy or girl to the front of the class and pose the child into the featured shape/pattern.

Some teachers, as previously mentioned, worked with the team member to deliver the lessons. Interestingly, all teachers (even those who asked for the boost) said the curriculum was easy to use. Teachers described that their students really liked the lessons and thought that they learned the new shapes/patterns. The teachers remained enthusiastic throughout the intervention period, and all said they would continue to use the pattern ABC lessons in the future.

Table 5 HLM multivariate models predicting just shape constructs, exploring standard versus boost interventions

Shape Constructs	Gender (ref = Male) Coefficient (*p* value)	Age Coefficient (*p* value)	Baseline Score Coefficient (*p* value)	Condition (ref = Control) Coefficient (*p* value)	Boost (ref = No Boost) Coefficient (*p* value)
Shape identification	0.22 (0.12)	**0.36 (< 0.01)**	**0.28 (< 0.01)**	0.27 (0.44)	**1.23 (< 0.01)**
Shape naming	0.08 (0.50)	**0.41 (< 0.01)**	**0.42 (< 0.01)**	0.20 (0.53)	**1.13 (< 0.01)**
Shape line drawing	0.08 (0.54)	**0.34 (< 0.01)**	**0.13 (< 0.01)**	0.23 (0.40)	**0.53 (0.04)**
Unaided real-world shapes	0.23 (0.26)	**0.70 (< 0.01)**	**0.14 (0.05)**	−0.28 (0.40)	0.35 (0.26)
Aided real-world shapes	0.13 (0.52	**0.47 (< 0.01)**	**0.30 (< 0.01)**	−0.07 (0.86)	0.50 (0.14)

The provided coefficients are standardized

Bolded numbers represent coefficients that are significant at a $p < 0.10$ level

Highlighting School 10

School 10, an intervention school, provides an interesting case regarding potential effectiveness of the Pattern ABC intervention. The graphs in Fig. 5 highlight pre-and post-intervention performance with School 10 in orange and the other intervention schools in gray.

There were 20 participating children (eight boys and twelve girls) in School 10, with three four-year-olds, eight five-year-olds, and nine six-year-olds. The ECE class had an additional 30 students who were not part of the study. Average scores for the various constructs resembled those of other intervention schools at baseline; however, after the intervention, School 10's average scores were greater than other intervention schools for many of the items. This school showed more change than others; there was a steeper slope from baseline to post-intervention. School 10 was one of the schools where there was a boost. An intervention member assisted (but did not take over for) the teacher in the classroom on six of the nine lessons. The School 10 teacher was younger than the other teachers and had the least experience in the classroom. She was one of the most excited about working with the team member and seemed very interested in innovative approaches in her classroom. Despite these observations, the available data prevent us from knowing why students in this school outperformed others.

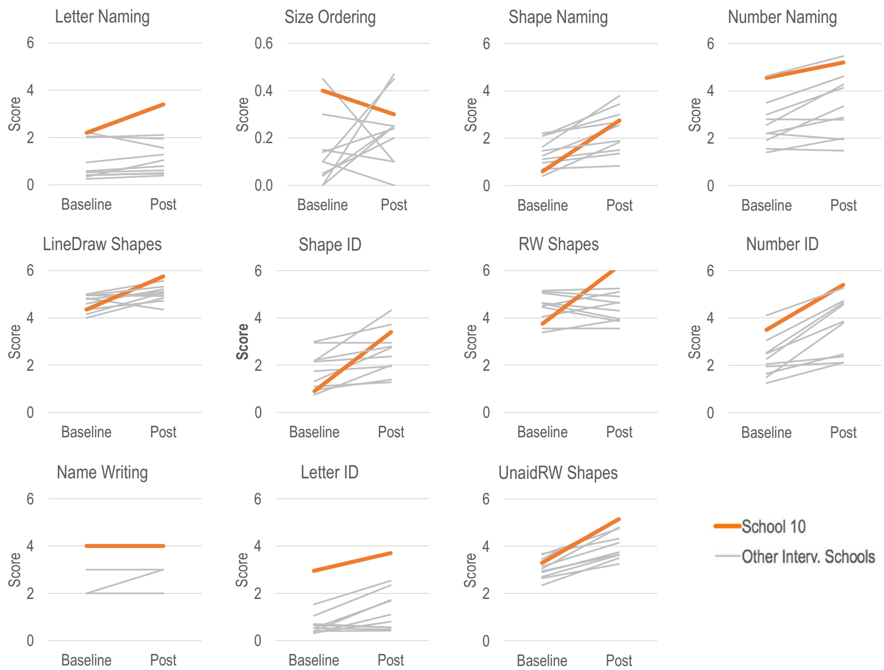

Fig. 5 Scores from only the intervention schools, with School 10 highlighted

Discussion

This study found that a school-based intervention in Tanzania could enhance children's spatial abilities and foundational skills. Researchers found that the Pattern ABC system could be effectively deployed through a school-based intervention, although variation was certainly observed across these schools. Data from this study shows that, at a rudimentary level, children's spatial abilities relate to their literacy and numeracy skills.

The intervention's Effect on Spatial Skills

While we did not observe huge gains, data from this study reveal that participating rural children did learn spatial skills from this educational intervention. Especially children in "boost" classrooms improved in their shape identification, naming, and matching to line drawings. The seven-week intervention resulted in improved learning outcomes most similar to topics and lessons previously taught by the ECE teachers (shape identification, shape naming, and matching shape line drawings); it was not as successful in improving children's knowledge of less familiar shapes and more abstract patterns (unaided and aided identification of real-world shapes). We found that most participating children were unable to connect shapes and patterns with real-world photographs, a skill that may be more challenging to teach and require a higher order of learning than shape naming, identification, and matching.

The normative environment of Tanzanian classrooms may explain why children improved on the lessons that were most linked to what teachers already knew and would likely teach in their traditional manner (shape identification, naming, and matching line drawings). Prior to this intervention, teachers reported that they had never asked their children to match shapes and patterns to real-world items nor form shapes out of their objects and bodies. The intervention asked teachers to use a different and novel instructional approach than they were used to doing. Even though teachers were excited about having children find shapes and patterns in their environment, less than half of the teachers brought their students out of the classroom to do this exercise. Perhaps if teachers had children engage more in the lessons, the children might have learned more from the Pattern ABC program. Educators recommend that children's meaningful construction of geometric and spatial ideas come by actively using slides, flips, turns, and magnifications (Battista, 1999); we still recommend that such activities occur in ECE programs.

With respect to our second study question of whether a group of Tanzanian teachers could use the Pattern ABC cards effectively in ECE programs, our results are encouraging but not conclusive. Teachers offered enthusiastic support of the curriculum, reporting ease in delivery and high appeal and understanding among their students. The teachers told the team members that they enjoyed the program and would continue to use it in the future. We are concerned that there may be some research bias here where the teachers told the team members what they thought they would want to hear. Future observations, outside of research study scenario, would allow us to know if teachers implement the curriculum on their own.

While significant in some respects, the impact of the intervention was somewhat disappointing; we had hoped to observed greater gains. We knew that this curriculum required that teachers engage students in learning activities quite different from the typical didactic norm used in Tanzania. In other locations, play-based approaches can promote more student learning than rote pedagogy (Hirsh-Pasek et al., 2004); researchers have found that play in ECE programs is linked to enhanced student achievement in a range of domains, including oral language and numeracy skills (Stagnitti et al., 2016; Wai et al., 2009). Thus, introducing and promoting this type of pedagogy, even at a minimal level, was an achievement.

While the study shows that it is possible to implement the Pattern ABC system in a low-resource setting in Tanzania despite external challenges (i.e., low teacher ratios, poor infrastructure, and limited teacher training), the large differences in performance of children across the various schools is an indication that some schools and teachers were better primed than others to utilize the learning intervention successfully. We did monitor the intervention, but we are unclear as to the fidelity of the curricula's administration when team members were absent. The better performance of the children in the boost schools, that is, the schools that received extra assistance from the intervention team, shows that the intervention, while teachable, may require a new and more playful approach to teaching in this environment. Possibly, the intervention introduces concepts and a teaching style that may be too distal from normative Tanzanian pedagogy to effectively implement without more explicit support by the Ministry of Education, community, and parents.

Similar to what has been observed in other low-income and crowded educational settings, we saw that many of the participating study teachers were strict disciplinarians. They rigidly controlled their classrooms, even having the youngest children sitting attentively. Especially in advance of this work, when our team members visited, they observed organized and demanding classrooms. We cannot know whether or not the teachers were creating such an environment to impress the visitors, but we suspect this was a regular approach used to keep order in small rooms with around 50 five- and six-year-olds.

This study provides important educational data on rural Tanzanian children. We observed significant associations between children's literacy numeracy and spatial skills, but these relations are only of low and moderate strength though. Without implying causality, this work shows significant, positive, and moderate correlations. Children who are good at identifying letters are also good at identifying numbers and shapes. Those who can name their numbers can also name letters and shapes. Interestingly, these correlations also appear for the aided and unaided real-world shapes. As age was a significant predictor in many of the outcomes, we believe that some of the skills may be learned outside of the classroom. Older children may have more exposure to concepts like matching and counting in their home lives.

Presence of skills identifying real-world shapes correlates significantly with practically all the other assessed skills. One caveat to these findings is that, because so many children scored at the floor of our measures, it could be the consistent lack of skills that drives the correlations among the tested constructs. As so few studies exist on this population, this information serves as an initial platform to continue further investigations.

The low level of performance among the majority of participating students at baseline is distressing. These were tests of academic achievement, and most children were unable to show even basic skills. It is notable that after only seven weeks, we observed measurable positive change, albeit small, in three fundamental aspects of spatial reasoning (shape identification, shape naming, and matching shape line drawings).

This of one of the extremely few educational studies of this type to be conducted in rural Tanzania; the provided data offer important insight on schooling in a low-income, resource-poor area. As noted previously, the children in our sample of three- to seven-year olds could only identify and name one or two letters of the alphabet and two or three numbers. Shapes identification and naming were also weak; the typical child in this sample was familiar with only one or two of the tested shapes. Among other studies with vulnerable preschoolers from Rwanda, India, and Haiti, there was a similar situation with children having low levels of shape awareness, literacy, and numeracy (Borzekowski et al., 2019; Borzekowski et al., 2019). In the Rwandan study, children who were six to eight years old could only name an average of 2.9 out of nine shapes (Borzekowski, Lando, et al., 2019). Among 1304 four, five and six-year-old children from Lucknow, India, children could identify an average 2.2 out of four shapes (Borzekowski, Singpurwalla, et al., 2019). Findings from a study of Haitian children's literacy and numeracy showed similar low-performance levels in basic literacy and numeracy skills (Fluent 2016).

Implications

This research considers the effectiveness of delivering the Pattern ABC system in rural Tanzania ECE programs. At the most basic level, the data show that the system can effectively be implemented in low-income, resource-poor schools. It shows that it is possible to use a different pedagogical approach, but more needs to be done. Typically, teachers in sub-Saharan Africa use a strict approach in the classroom. Altering instructional techniques and enhancing teacher-coaching can improve children's education and skills (Conn, 2017). In this intervention, we observed when the teachers had more training and support (at least at the level provided to teachers in our "boost" schools), students performed better on many of the outcomes.

Our team found that teachers in the intervention group enjoyed using the Pattern ABC system. They welcomed the new curriculum, and several asked for additional help so that the intervention would be more successful. Assistance in the class, in effect reducing the teacher to student ratio, may be key to better outcomes in ECE programs.

There is more work to be done to explore the Pattern ABC system's full potential in locations such as Morogoro, Tanzania. This study was a preliminary test and more extensive work needs to occur to completely answer questions about the system's usability and educational impact. This was just one setting, and clearly we would need to try this setting in other locales with different populations. We recommend that in trying to work in new settings that there is continued effort to work with local school administrators, policymakers, teachers, and parents; it is critical to have this program fit within a setting for it to be valued and accepted. In doing similar work, we strongly advise as do others that adaptations of activities and measures reflect the local culture and values (Mwaura & Marfo, 2011).

For this work, we tested the Pattern ABC program in schools with teachers offering the lessons. A strength of the program is that it can be delivered in many ways. Parents and guardians could use the cards and do the activities with children at home. As well, we believe that educational media can deliver similar lessons, especially illustrating how these shapes and patterns appear in the real world. A preschool program, such as *Akili and Me* which reaches millions of children in sub-Saharan Africa, could incorporate the Pattern ABC into its episodes, teaching viewers about shapes and patterns like it does with letters and numbers.

While the developed instruments provided insights into some basics, many of the assessments were oriented toward testing children's receptive skills (such as shape identification) and did not include measures (other than name writing) of equal importance such as children's productive abilities, like the ability to draw basic shapes and forms. Children learn to write through imitative drawing and symbolic markings, progressing through stages of emergent writing formation that include scribbles and shapes (Byington and Kim, 2017). Just as early writing skills have been shown to be predictors of children's future reading and writing skills (Puranik and Lonigan, 2012) is it likely that children's emergent spatial drawing skills are linked to future spatial reasoning and other skills (such as reading and writing). Additionally, developing spatial skills among children can enhance a variety of related and transferrable mechanical abilities (Uttal et al., 2013). Many intellectually-talented students show strong spatial abilities that are distinct from literacy and math achievement (Tzuriel and Egozi, 2010). This linkage is worthy of further exploration.

To alter contemporary neglect of educators in promoting spatial reasoning (Wai et al., 2009), it is critical to disseminate the importance of spatial reasoning and provide viable interventions. This can be done on a global level. Studying the effects of an easy-to-use curriculum enhancing young children's spatial skills in an under-resourced part of the world brings us closer to this aim.

Acknowledgements The researchers appreciate the implementation and data collection research teams in Morogoro, Tanzania. They are also grateful for the participation of the teachers and children who provided time and data to better understand the impact of this intervention.

Funding This study was commissioned by Na2ure and was made possible through the generous support of the Radius Foundation.

Data Availability All data and materials referenced in this paper are available upon request from the corresponding author.

Declarations

Conflict of interest The authors have no conflict of interest with the information shared in this paper.

Ethical Approval Prior to the start of research, the study's protocols and instruments received approval from the Tanzanian Commission for Science and Technology (COSTECH) and the University of Maryland's Institutional Review Board.

Consent to Participate This research used active parental consent and active participant consent.

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