Journal on Mathematics Education
Volume 16, No. 3, 2025, pp. 871-888

Empowering early childhood educators to foster spatial and numeracy reasoning through play-based learning

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Received: 17 April 2025 | Revised: 18 August 2025 | Accepted: 20 August 2025 | Published Online: 23 August 2025

Abstract

Despite the growing awareness of the importance of spatial reasoning in schooling years, there is a notable gap in research literature to promote spatial reasoning in early childhood education in Indonesia. This research aims to address this gap by building the capacity of Indonesian early childhood educators in designing play-based activities to support children's spatial thinking and reasoning. Twenty early childhood education (ECE) educators coming from different area in Java, Indonesia participated in the study. The study employed design-based research methodology to examine the way in which research team and ECE educators work collaboratively to bring about innovative learning processes and changes in ECE's practices. A key design principle of the study features play-based activities to promote children's spatial reasoning skills in the early years were analyzed. This study finds that the professional learning program provides support for ECE educators in three areas, such as foster an understanding of key numeracy concept including one-to one correspondence and cardinality and how it is being implemented, offer insights about spatial ability and its constructs, and exposure to spatially rich play-based activities that could be adopted for ECE centers.

Keywords: Early Childhood Education, Educators, Numeracy, Play-Based Learning, Professional Development, Spatial Reasoning

How to Cite: Winarti, D. W., Widjaja, W., Razi, F., Huzaimah, S., Prianggi, A., & Setyawan, I. A. (2025). Empowering early childhood educators to foster spatial and numeracy reasoning through play-based learning. *Journal on Mathematics Education, 16*(3), 871–888. https://doi.org/10.22342/jme.v16i3.pp871-888

Early childhood education (ECE) educators play an important role in the formative years of children to develop and offer rich spatial reasoning activities to support later development of numeracy learning. Sinclair et al. (2011, p. 135) stated "*if we expect children to learn and apply spatial-visual approaches, it is important to ensure that mathematics teachers are well-prepared to recognize and apply such reasoning themselves*". Furthermore, young children engage with mathematical ideas, including spatial reasoning in their home prior-to-school. Research shows many young children can engage in mathematically sophisticated ideas and come to school with these skills (Clements & Sarama, 2020). Clements and Sarama (2020) explained that young children are capable to read maps, including identifying places on maps, identifying landscapes features on maps and aerial photographs, as well as locating familiar places on maps. Providing rich learning experiences that allow children in early childhood to engage in exciting learning activities where mathematical reasoning and thinking and multiple ways of solving a problem are vital.

Spatial skill has a strong positive correlation with mathematics, including numeracy (Cheng & Mix, 2014; Lowrie et al., 2017) and this skill is significant in promoting school readiness (Wai et al., 2010). Previous studies have shown that various play-based interventions, including hands-on activities such as block play (Casey et al., 2008), puzzle games (Levine et al., 2012), mental rotation training (Cheng & Mix, 2014), and digital play (Polinsky et al., 2022), improve spatial reasoning and support the development of numeracy and cognitive functions in early developmental stage of young children. In the Indonesian context, the promotion of spatial reasoning in mathematics at the formal school level has begun to be documented by several studies, for instance, at the elementary school level (Putrawangsa & Patahuddin, 2022) and secondary school levels (Patahuddin et al., 2020, Winarti, Patahuddin et al., 2024), but at the ECE level remains underexplored.

Promoting spatial reasoning and numeracy through play-based learning at the ECE level requires educators' professional readiness and knowledge (Lazzara et al., 2024). However, access to ECE educators' professional development in Indonesia is still limited due to obstacles of distance, competencies, policies, and equality of opportunity (Lim et al., 2020; Susanti & Pramono, 2024). Hence, there is a notable gap in research literature to promote spatial reasoning for early childhood education in Indonesia. This study aims to address this gap by supporting ECE educators to promote spatial and numeracy skills.

In Indonesia, ECE was recognized as part of the national education system in 2003 following the establishment of the Directorate General of Early Childhood Education in the Ministry of Education and Culture (MOEC) in 2001 (Hasan et al., 2013). In the development of early childhood education in Indonesia, there has been an attempt by the Directorate of Early Childhood Education to encourage play-based activities as part of its commitment toward the implementation of SDG 4.2. It is shown in the structure of the Early Childhood Education curriculum that emphasize on the meaningful play-based activities to provide space for exploration to support the development of children's characters and competencies (MoERCT Indonesia, 2024).

Play-based activities is in line with the program of smooth transition from ECE to primary education as promoted by the Indonesia's Ministry of Education, Culture, Research, and Technology through the 24th episode of *Kurikulum Merdeka* (Freedom Curriculum episode 24th) (retrieved from https://direktoratsd.id/transisipaudsd/). The core idea of the smooth transition is to ensure the positive learning motivation of reading, writing, and counting (MoERCT Indonesia, 2024) by first is the removal of the entrance tests to primary school in reading, writing, and counting. Second is the need to embed at least two weeks of primary school orientation for new children. Lastly is the implementation of the six foundations of a child's development as low primary level learning outcomes. Different from primary level, the first target of the program articulates play-based activities of reading, writing, and counting in ECE.

This study aims to develop ECE educators' capacity in designing play-based activities to promote children's spatial reasoning and thinking in the early years. A professional development (PD) program over 3 days was designed to offer ECE educators first-hand experience with play-based spatial reasoning activities. The assumption was that PD opportunities would empower the ECE educators to adapt and design spatial reasoning activities based on the needs of their own centres. In addition, the PD was also expected to promote the quality of ECE. These expectations are in line with SDG 4.2 that aims to assure education access for all children, good quality parenting and pre-school education so that children are ready and well prepared for primary education. This study, therefore, addresses the following question:

To what extent does the professional development program support ECE educators in designing play-based learning activities that support children's spatial reasoning?

Spatial Ability's Construct and Spatial Reasoning

Spatial ability is the ability to formulate or manipulate, transform, and generalize a mental image in the mind, and the relationship between the parts of this image (Battista, 2007). Despite the various opinions on the dimensionality of spatial ability (Yilmaz, 2009), this study adopts the spatial constructs used by Lowrie et al. (2017) namely spatial visualization, spatial orientation, and mental rotation. Each of the constructs is elaborated briefly as follows.

Spatial visualization is described as the ability to do some multistep objects' manipulation such as mentally folding and unfolding paper in a systematic way, twisting, or inverting objects (Linn & Petersen, 1985). Spatial orientation is generally considered as the ability to imagine the appearance of the objects from the observers' different orientations (French, 1951). Lastly, mental rotation is described as the ability to mentally rotate a two-dimensional (2D) or three-dimensional (3D) figure (Shepard & Metzler, 1971).

Spatial reasoning needs an awareness about space, the capability in imagining objects and relationships as well as in using this information to reason and solve problems (National Research Council, 2006). Spatial reasoning in itself is not easy to be measured as it involves awareness and imagination, which might not be simply shown. Within the context of education, spatial reasoning goes beyond the result of spatial ability tests, as mostly conducted in the psychological department. Teachers need to be provided with tools to recognize and urge awareness of space and to promote them in recognizing spatial relations during their daily interaction (Harris, 2021).

Spatial Reasoning and Numeracy Reasoning

There is ample evidence that shows the positive correlation between spatial ability and mathematics. Those who performed better in spatial tasks tend to also perform better in mathematics tests (Hegarty & Kozhevnikov, 1999; Xie et al., 2020). In more specific strands of mathematics like numeracy, studies show the important role of spatial reasoning ability to build children's patterning skills (Clements & Sarama, 2011), their pattern structuring (Mulligan & Mitchelmore, 2013), and their understanding of quantity (Newcombe et al., 2015). A study by Crollen and Noel (2015) showed that children who have high visuospatial skills performed better than their counterparts with low visuospatial skills not only in numerical tasks specifically but also in other tasks that require them to be able to represent number magnitude.

Spatial training itself can support the development of children's numerical reasoning. A study from Cheng and Mix (2014) showed that children's ability in solving missing term problems is improved after completing mental rotation training. Cheng and Mix (2014) posited that children might rotate the equation mentally rather than go into deep conceptual changes. In addition, mental rotation training improved children's visuospatial working memory which supported better calculation. Another study from Hawes et al. (2017) revealed that spatial intervention is an effective means to improve children's spatial reasoning and improved children's ability in symbolic number comparison. The experience of linking various spatial representations with number words repeatedly might be helpful in the acquisition of number sense. Therefore, the improvement in spatial thinking might provide one of the means to strengthen number sense. In the Australian curriculum, spatial reasoning is included in the foundational component of numeracy (ACARA, 2010).

Play-based Pedagogy

In the early childhood context, children engage in spatial learning experiences during physical play, including when toddlers and young children play, ride bicycles, and move objects. Lee (2012) calls for a holistic, integrated, play-based, and child-centered program that offers young children's opportunities to engage with meaningful mathematical learning experiences. It is also important to debunk a misconception that play-based learning does not simply lead to 'the big ideas' of mathematics through play (Clements & Sarama, 2009). Dockett and Perry (2010) noted that ECE educators' ability to maximize the learning opportunity in play requires mathematical knowledge among other things. The ECE educators play an important role in designing and facilitating children's learning by making the key mathematical ideas and concepts visible and encouraging children to communicate their reasoning. Earlier studies highlight that intentional planning of play-based activities leads to more effective learning (Schimdt et al., 2018; Rahayu et al., 2022).

Researchers have identified different types of play, including sensorimotor / manipulative, which may involve rhythmic patterns, and exploring manipulatives or objects such as sand, play dough, or blocks; and symbolic/pretend (Monighan-Nourot et al., 1987), which may involve manipulating or constructing something. Clements and Sarama (2020) advocated the importance of well-structured and guidance by ECE educators when implementing play-based pedagogies, including when using dramatic, make-believe play, and the use of small-group discussions.

Bubikova-Moan et al. (2019) conducted a systematic literature review about ECE educators' perceptions on play-based learning. They identified several studies that highlighted the struggles faced by ECE practitioners in positioning themselves in play, particularly in balancing their role and respecting children's agency as autonomous players and learners. An ongoing engagement and refinement of how play-based learning in early childhood education is conceptualized and the extent of ECE involvement in play is needed.

Within the designed PD Program, ECE educators learned about these three spatial reasoning constructs and how to integrate them within their learning activities to support children's numeracy learning and their development of reasoning skills. In order to provide insights for ECE educators, spatial reasoning activities were introduced and discussed during the PD Program. For example, pentomino challenges and building blocks (Hawes et al., 2017) required ECE educators to form as many tile/block configurations as possible. These activities require ECE educators to utilize their spatial visualization and mental rotation skills. Another example is finding hidden objects (Stea et al., 2004) that required ECE educators to use their spatial orientation skills. These activities are well-aligned to support the development of other numeracy priority areas in early years, such as patterning, counting, numeracy and measurement (Lee, 2012).

Professional Development (PD) of ECE Educators

Educators, especially in early childhood education, play a crucial role in shaping educational quality across formal schooling and informal teaching setups. Indonesian government regulations mandate specific qualifications and competencies for educators, covering pedagogical, professional, personality, and social aspects (Government of Indonesia, 2005; 2017). These standards emphasize educators' responsibilities in planning, implementing, and evaluating learning processes for young children. Improving the professionalism of ECE educators demands multifaceted efforts, necessitating reliable governmental policies to enhance educator's development (Syafril et al., 2021). Professional educators are instrumental in understanding and catering to the diverse needs of children, fostering high-quality human resource development. Some studies from Europe, such as Sylva et al. (2007) and Early et al. (2006) suggest that investing in the training and PD of early childhood caregivers and educators can lead to significant improvements in the quality of ECE. Well-trained caregivers can create a positive learning environment, promote children's development, and increase job satisfaction. Clement and Sarama (2011) on their study of early professional development in geometry topic show that the PD holds potential to bring significant difference in early years children's learning.

There are common misconceptions about approaches in supporting numeracy learning in the early childhood context. Lee and Ginsburg (2009) identified common misconceptions among ECE educators, such as viewing language and literacy are far more important than mathematics in the early years and young children have limited capacity to learn mathematics. This underscores the need to build ECE educators' own knowledge and confidence to provide rich mathematical learning experiences for young children. Quality PD programs using evidence-based research have been developed to offer comprehensive, rich and meaningful numeracy learning experiences in early years.

METHODS

Design-Based Research (DBR) entails both the design of learning environments as a means to come to understand innovative learning processes and the way in which those learning processes can be supported (Cobb et al., 2003). This research project employs DBR methodology (Design-Based Research Collective, 2003; Van den Akker et al., 2006) which consists of three phases: 1) preparation and design, 2) teaching experiment (i.e., PD Program) and 3) retrospective analysis. We elaborate each phase as follows.

Preparation and Design

The preparation phase started with research on literature around spatial reasoning and play-based activities in early childhood education. We studied the significance of promoting spatial reasoning in early childhood education in Indonesia to identify the gap for the present study. We then expanded our study to the concept of play-based pedagogy and why it fit for ECE. Finally, we studied how to support ECE educators to be able to promote spatial skills and found that studies about PD for early childhood are scarce in the Indonesia context.

Sourced from the preliminary study of literature, we identify the key features of play-based activities to promote children's spatial reasoning skills in ECE (Winarti et al., 2024). We use these key features as materials in designing the Professional Development (PD) program for ECE educators.

ECE Educators Professional Development (PD) Program

A key feature of DBR is the way in which practitioners and researchers work collaboratively to bring about innovative learning processes and changes in practice. DBR requires that educators are prepared and supported in developing a knowledge base sufficient to support the constructive process, both for individual children and for children-to-children and children-educators' interactions. Hence in this project, deliberate attention was paid to design a learning continuum to support ECE educators in shifting from the traditional approach to play-based spatial activities in fostering children's numeracy learning in early years.

This PD was intended for ECE educators, and it was announced to the public through social media. Twenty-five ECE educators from various regions around Java province were registered but only 20 educators could participate on site, as summarized in Table 1.

Table 1. Participants' demographic data

Participants (E = Educator)	Area of Center	Level (KG = Kindergarten; PG = Playgroup)	Teaching Experience (Years)	Educational Background
E1	Jawa Barat	KG B	15	Bachelor in Education
E2	Jawa Barat	KG A	17	Master in Education
E3	Jawa Barat	KG A&B	10	Bachelor in Education
E4	Jawa Barat	PG	20	Bachelor in Education
E5	DKI Jakarta	KG A&B	1	Bachelor (non-Education)
E6	Jawa Timur	KG B	19	Master in Education
E7	Jawa Barat	KG A	18	Master in Education
E8	Jawa Barat	KG B	7	Bachelor in Education
E9	Jawa Barat	KG B	20	Bachelor in Education
E10	Jawa Barat	KG A	3	Bachelor in Education
E11	Banten	KG B	5	Master in Education
E12	DKI Jakarta	KG A&B	12	Bachelor in Education
E13	Jawa Barat	KG A	1	Bachelor in Education
E14	Jawa Tengah	PG	12	Bachelor in Education
E15	Jawa Barat	KG A	21	Bachelor in Education
E16	Jawa Barat	KG A	18	Bachelor (non-Education)
E17	Jawa Timur	KG B	23	Master in Education
E18	Jawa Barat	KG B	2	Bachelor in Education
E19	Yogyakarta	PG	4	Bachelor in Education
E20	Jawa Barat	KG A&B	10	Bachelor in Education

The PD program was designed as a series of activities that include co-designing, implementation and dissemination of the implementation results to identify the opportunities and challenges in order to refine the design. This paper, however, focuses only up to the co-design activities among PD participants which captured key features of the PD to promote ECE educators' spatial reasoning skills and support them in designing spatial reasoning activities using play-based pedagogies. The overview of the PD program is presented in Table 2.

Table 2. Summary of activities within educator's PD program

Event	Activity
Introductory (via zoom)	The introduction session consists of the following activities: 1. Overview of the research project, introducing the research team, the significance of the research, research design and data collection 2. A lecture on reasoning, spatial construction through play-based and the importance of knowing the potential for learning numeracy from early age
PD Day 1	1. Seminar a. Numeracy learning within the context of Early Childhood Education b. Skills development focusing on early counting, one-to-one correspondence, and cardinality principles. c. Pedagogical considerations in teaching numeracy in the early years' context 2. Play-based activities

Event	Activity
	3. Exploration of spatial constructs (Spatial visualization, mental rotation, spatial orientation)
PD Day 2	Design play-based activities for spatial reasoning in the early years Gallery walks and sharing ideas through presentations
Implementation	Implement the design of play-based activities at their respective center and collect evidence of the implementation
Follow-up PD	Disseminate the result of the implementation Focus group discussion to share and reflect on key findings from the implementation including opportunities and challenges

Data Collection

In order to gain a comprehensive understanding of the study, authors triangulated the data collection by gathering more than one data source through observation and artefacts' documentation. Data triangulation aims to enhance validity and reliability of this study as more than one data could cross-validate the information obtained (Green et al., 2006).

All sessions during the PD were recorded and the recording was stored on a shared drive, accessible only by the authors for observation and analysis. On the second day of the PD, participants worked together in groups of four or five to design play-based activities that potentially promote children's spatial reasoning and numeracy. These groups were formed based on the class that they taught in their respective center. They are in a group for Kindergarten A (TK A), Kindergarten B (TK B), and playgroup (KB). Their designs were written in the form of a poster and posted on the wall. During the gallery walk each group presented their poster to the audience and discussed. Authors then documented the posters physically and in a soft file for further analysis.

Data Analysis

A retrospective analysis was conducted to analyze the data. The inductive process was carried out in analyzing the data, both recording and artefact (i.e., posters), to obtain a thorough comprehension of the emerging themes, patterns or relations (Creswell & Creswell, 2018). The analysis was guided by Ramful et al.'s (2017) spatial reasoning constructs, the complexity of spatial reasoning in Davis and spatial reasoning group (2015), the element of numeracy defined by ACARA (2010) as well as the play-based learning concept by Robertson et al. (2018). Noteworthy, to minimize bias in data analysis, authors themselves were being reflective on the process of analysis by questioning their assumptions and exploring themes for possible interpretation (Creswell & Creswell, 2018).

The final stage in data analysis was synthesizing the findings to provide comprehensive understanding of the research topic. The conclusion was obtained based on the entire research process, from the literature review, PD program and findings, to highlight the essence of the study. This conclusion is then supported by relevant research, offering a well-rounded perspective on the role of giving support for ECE educators in promoting spatial and numeracy reasoning.

RESULTS AND DISCUSSION

We present the result of the data analysis to answer the research question: T*o what extent does the professional development program support ECE educators in designing play-based learning activities* that support children's spatial reasoning? We orchestrate our analysis's presentation in two parts:1) Key features of PD Program that promote educators' spatial reasoning and numeracy skills, 2) Key features of spatial reasoning and numeracy concepts within play-based activity designs.

Key Features of the PD Program in Promoting Educators' Spatial Reasoning and Literacy of Numeracy

This section elaborates the analysis results of the PD Day 1 that was observed via the video recording data. The PD was orchestrated to provide understanding of the concept of numeracy and spatial reasoning as well as to provide hands-on experience for PD participants in spatial play-based activities. From the observation, we elaborate our findings based on the topic of the session as follows.

Numeracy Learning Practices in the ECE Context in Indonesia

In this session, participants were tasked to explore numeracy and their relationship with mathematics and discussed strategies in teaching number concepts to children This session was designed to promote ECE educators' capacity in developing children's numeracy environment with the expectation that it will impact the effectiveness of learning (Wood & Frid, 2005). In explaining the concept of numbers that can be introduced to early childhood children, the research team emphasized understanding of estimating and principles in numeracy such as counting, one-to-one correspondence, and cardinality. Understanding these concepts will help educators to determine effective activities in building numeracy skills (Siemon et al., 2012).

Furthermore, the session also included a reflective component where the research team provided feedback regarding the numeracy problems experienced by participants in their respective classes and linked it to the material and discussion in this session. One of the educators said that the problem with numeracy in the classroom was that children could count but miss out on numbers, or their counting was limited to certain numbers. Therefore, the research team invited participants to analyze several videos related to children's numeracy activities and their difficulties when learning numbers. Through this activity, educators could anticipate several children's errors in ordering numbers (counting) such as not counting objects one by one or mentioning each number more than one (one-to-one correspondence) and not ending the calculation clearly (cardinality). This forum encouraged educators to discuss specific issues related to numeracy learning in their classrooms with other educators (Goos et al., 2014). Noteworthy, as many studies found (e.g., Brannon, 2002; Starr et al., 2013), that the issues in learning numeracy, aforementioned, can be anticipated by developing numeracy knowledge in the classroom. Analyzing possible errors and discussing the concept of counting, one-to-one correspondence and cardinality could also promote educators' better understanding of these concepts. In consequence, educators are more prepared to teach the children which then potentially could improve children's learning outcomes.

Play-based Activities to Support Spatial Reasoning

In this session, ECE educators were introduced to three play-based activities designed to promote spatial reasoning that consist of spatial visualization, mental rotation and spatial orientation (Ramful et al., 2017). The research team led the first activity and discussion where educators explored their spatial visualization thinking by constructing symmetrical shapes using connected cube blocks (Figure 1a). Block activities have been used by several spatial reasoning studies (e.g., Winarti, 2018) and have proven to be a tool used to promote spatial visualization skills. In addition, block activities provide individuals with the opportunity to visualize and transform objects in their minds to reason about space (Verdine et al., 2017; Schmitt et al., 2018).

In the second activity, educators were exposed to mental rotation and spatial visualization thinking in which they worked on constructing symmetrical shapes by using tangram (tangram activities) (Figure 1b). In tangram activities, individuals are stimulated to rotate mentally (Levine et al., 2012). It requires individuals to rotate and manipulate pieces of tangram according to a certain construction (Kmetová & Nagyová, 2021). In addition to mental rotation, ECE educators also employ their spatial visualization skills where they need to visualize the construction of shape while arranging the tangram shapes to match or reflect the previous tangram construction.

In the third activity, ECE educators explored spatial orientation thinking by working on a task in finding location using a map as well as drawing a map. Noteworthy that finding location/map activities could effectively increase spatial orientation skills (Gowers, 2020). While doing this activity (Figure 1c), participants mentally oriented themselves towards directions such as going up, going down, turning right, turning left, moving forward, and moving backwards in anticipation of the location from a different point of view (Hegarty & Waller, 2005).

After these activities, led by the research team, participants evaluated the games played and analyzed the reasoning process. In this sense, participants recalled back what they had done, like rotating, twisting, or shifting the tangram shapes or cube blocks in mind before using their hand to move them or what they thought while finding the location or drawing the map. Participants then realized what they have done were spatial reasoning activities and they have done that in their daily life too without knowing the terms.

1a 1b 1c

Figure 1. Samples of Participants' Spatial Activities

Exploration of Spatial Constructs (Spatial Visualization, Mental Rotation, Spatial Orientation)

To promote ECE educators' understanding on the concepts of spatial construct as well as to train their spatial thinking skills, the research team provided tasks for ECE educators to work on items that required spatial thinking skills. Prior to working on the task, the research team recalled the definition of spatial ability that has been described in the PD introduction session (see Table 2) as educators required to utilize those spatial constructs to work on the task.

The research team also provided problems that the ECE educators worked on to explore spatial reasoning activities. Some of the problems explored are related to spatial reasoning, such as cube nets (spatial visualization), Ferris wheel (mental rotation), and a person's perspective on an object (spatial orientation), which are adapted from Ramful's (2017) Spatial Reasoning Instrument (SRI). Through this activity, the educators are expected to have strategies to solve spatial reasoning activities and be able to differentiate the three constructions.

Summary

PD program day 1 was designed to provide scaffolds for ECE educators to understand the concept of numeracy and spatial reasoning. In terms of numeracy skills, participants recalled the concept of counting, on-to-one correspondence and cardinality which are the three main components of number sense. In addition, the video analysis of numeracy learning provides scaffolding for educators to be ready with various anticipation on what can be happening in the classroom for numeracy learning.

In terms of spatial reasoning, participants did hands-on play-based spatial reasoning activities and worked on tasks to answer several written cases that require spatial thinking. These kinds of activities offer ECE educators' opportunities to utilize their spatial thinking ability which potentially make them understand better than just listening to a talk or seminar

Key Design Features of Spatial Reasoning and Numeracy Concepts Within Play-based Activity Designs

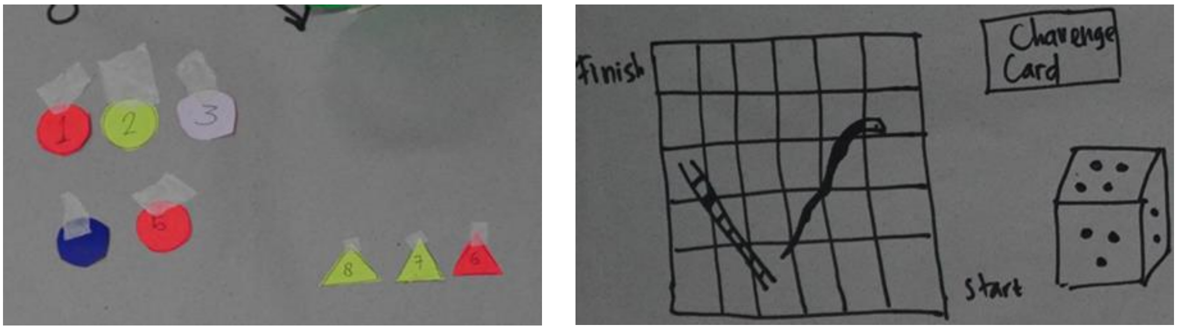
Using spatial reasoning skills is one of the elements of numeracy skills (ACARA, 2010). Therefore, building children's spatial reasoning skills is expected to be able to promote children's numeracy skills. Based on this idea, ECE educators were asked to design play-based spatial reasoning activities during PD Day 2. Data from the poster session was gathered and analyzed. From the data analysis, despite some similarities in the activities designed, we also identified some interesting and unique activities. The similarities are understandable because participants experienced the same PD program and the same activities, which might inspire them to design similar ones. The summary of key design features is described in Table 3 and is explored in more detail in conjunction with its potential to promote spatial reasoning skills which then could also, potentially, build children's numeracy skills.

Table 3. Key features of spatial reasoning and numeracy within play-based activities for each spatial construct

Spatial Construct	Topic	Key Features of Spatial Reasoning
Spatial visualization	Introducing shape/ shape construction	Visualizing/mentally constructing the shape (e.g., cuboid, cube, sphere) and identifying its shape concrete representation of shapes
	Observe/ build a symmetrical object	Visualizing/ mentally modelling the line of symmetry (vertical, horizontal or diagonal) then associate it with what they found in the surrounding
Spatial orientation	Way finding; Reading map/ drawing seating chart	Orienting oneself based on the direction given memorize/ recall information or location, Graphical representation
	Position	The use of spatial language (direction, position)
Mental rotation	Puzzle game; Tangram game	Mentally rotate, flip the shape to match the pattern on the puzzle/ tangram

The Spatial Reasoning Activities with Explicit Numeracy Thinking

There were number of activities designed by ECE educators which were not only focused on spatial reasoning activities but also explicit numeracy thinking. In this sense, the activities might require multiple thinking skills as exemplified in Figures 2a and 2b. The example in Figure 2a shows material used for the activity of matching geometric shapes. This activity uses triangle and circle models in various colors and numbers. Children are expected to arrange the shape based on its colors, numbers or the shape itself. In this sense children might utilize their mental rotation and spatial visualization in arranging the shape, meanwhile at the same time, they also utilize their number sense in identifying the placement of the number to make them in order. Meanwhile, Figure 2b shows the description of a snake and ladder game that uses a dice and a board as the main game. In this game, children are required to visualize their move by combining the information of how many steps they need to move based on the number they got after rolling the dice and whether they need to move horizontally, climb up or move down based on the last position they have.



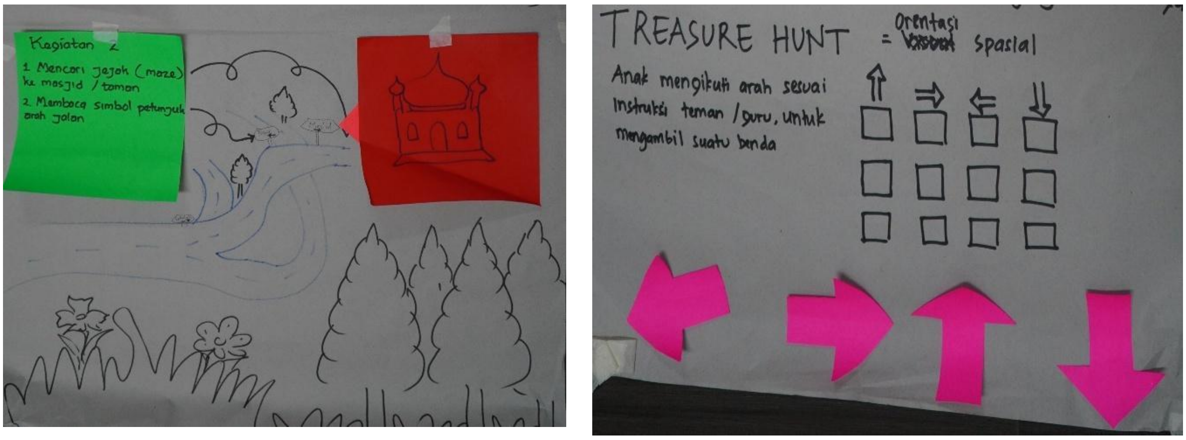
2a 2b

Figure 2. Description of an activity that promotes spatial and numeracy skills

The Spatial Reasoning Activities Focusing on the Spatial Reasoning Construct(s)

There are several activities designed by ECE educators that explicitly promote spatial reasoning skills on a certain construct or a combination of several constructs. Figures 3a and 3b exemplify the activities designed by ECE educators that focus on spatial orientation activities, namely map/sign reading and following instructions. Figure 3a shows the description of an activity where children are required to read signs given along the way to look for the location of a mosque and a park. In reading a sign, children are required to be able to orient themselves in the real location and relate it with the direction sign given. For Figure 3b, the activity was designed to get the children to follow the instructions given to them. Like Figure 3a, this activity requires children to be able to orient themselves toward their surroundings while receiving information on where to go in the given direction.

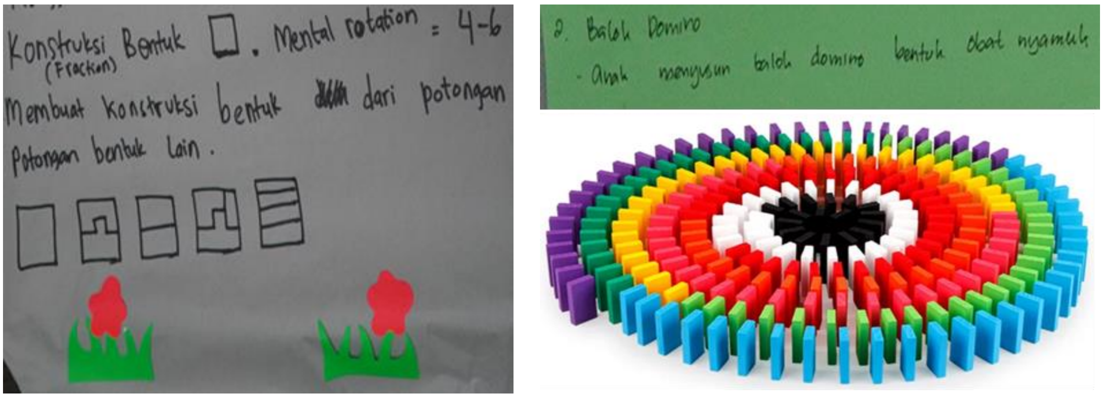
In addition, there are activities that were designed to promote children's spatial rotation and spatial visualization ability, as exemplified respectively in Figures 4a and 4b. The activity in Figure 4a requires children to build a rectangular shape from other pieces of shapes. In terms of constructing the shape, children might also use lots of spatial visualizations as they need to imagine what the shape would look like. However, in the process of visualizing the shape, children need to also rotate/ think about how to rotate the pieces of the shape to fit with the other piece.



3a 3b

Figure 3. Description of activities that promote spatial orientation skills

In Figure 4b, the illustration is given on how the building domino blocks would be look like as the instruction given is to build a circular shape from domino blocks. This activity is one of the examples of activities that promote spatial visualization skills of children. In this sense, children need to know what the circular shape looks like, then visualize the shape in their mind and start building the blocks by referring to the visualization of the circular shape they have in mind. This process might not be in one go, as children might build and re-built to get the proper shape as their visualization and along the process, the spatial visualization thinking is happening.



4a 4b

Figure 4. Description of activities that promote mental rotation and spatial visualization

Summary

PD program day 2 was designed to provide opportunities for ECE educators to be able to design play-based spatial reasoning activities to support numeracy learning. Even though they work in groups, the designs had come from the discussion of all group members. Each member brought their experiences which then enriched the activities that they designed. Through co-designing the play-based spatial activities and with the research team facilitating the session, participants have opportunities to gain more insight not only from experimental point view from varied educators but also research-based point of view from the research team. In consequence, participants could result in a comprehensive design to be implemented in their respective center.

CONCLUSION

This study highlights that the PD program for ECE educators designed in this study brings, not only, knowledge about numeracy, spatial constructs and play-based spatially reach activities but also hands-on experiences in designing spatial play-based activities in collaboration with educators from different centers and with research team which can later be adopted at the educators' respective center. Despite using what they have learned and experienced during PD sessions, interestingly, participants also utilized their own experiences during the design process such as using their respective local context and using recycled materials that are familiar around them.

This study shows the potential of the PD Program to promote educators' capacity, in this context is numeracy and spatial reasoning within play-based activities framework. However, there are limited numbers of PD programs for ECE educators compared to other school levels. From this study, now it is timely to inform the policy makers and education agencies on the significance of providing sufficient support for ECE educators and one of them via the PD program.

Despite the rich opportunities provided by the designed PD program, we also recognized some limitations of this study. The challenge faced by participants during the design process was their less understanding about spatial constructs. Even for most of them, the term "spatial reasoning" was novel. Another limitation was that this study did not observe the implementation of the designed activities at the participants' centers. Therefore, this study focuses only on participants, and their play-based spatial activities designs during the PD sessions. Further study can be conducted to also observe the implementation of the designed activities and study how early childhood children engage with the designed activities and look in more detail at how the designed activities could promote children's spatial reasoning and numeracy skills. In a more practical recommendation, longitudinal DBR could be conducted to design, test and refine the design to result in feasible learning design in promoting spatial reasoning for children.

Acknowledgments

The authors would like to thank the Faculty of Education, Universitas Islam Internasional Indonesia for funding this study. We also thank the in-kind contribution from the Deakin University and the Southeast Asian Ministry Education Organisation Regional Centre for Early Childhood Care Education and Parenting (SEAMEO-CECCEP). We also thank all the ECE educators' volunteers who were willing to participate in the PD Program and data collection and Mrs. Syifa Mufiedatussalam for helping us during the PD program.

Declarations

Author Contribution : DWW: Conceptualization, Formal Analysis, Review, and Writing.
WW: Conceptualization, Review and Methodology, and Writing.
FR and SH: Data Curation, Formal Analysis, and Writing.
AP and IAS: Writing.

Funding Statement : This study is funded by the Faculty of Education, Universitas Islam Internasional Indonesia and receive an in-kind contribution from the Deakin University and the Southeast Asian Ministry Education Organisation Regional Centre for Early Childhood Care Education and Parenting (SEAMEO-CECCEP).

Conflict of Interest : The authors declare that there is no conflict of interest.

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