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'Bear Hunt' Sparks Change: Using Lesson Study to Integrate Spatial Thinking in Early Childhood Design Education

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Abstract. Developing spatial ability in early childhood is crucial, but not all children are naturally drawn to spatial activities like construction. For those with different play preferences, integrating design and construction tasks with storybooks will engage them more, tapping into their problem-solving interests. Despite the central role of storytelling in early childhood education, it's relatively new for teachers to use stories to engage children in spatialized design assignments. This study addresses this gap by implementing a Lesson Study approach in six Irish junior and senior infant classrooms from two schools with ten teachers. Qualitative data from classrooms and teacher discussions reveal positive outcomes: teachers altered their lesson strategies, gained insights into their students' spatial thinking, improved spatial design assignment development, and enhanced selfefficacy in conducting spatialized lessons. These outcomes underscore the efficacy of Lesson Study for professional development in early childhood spatial education.

Keywords: Spatial Thinking · Lesson Study · Design Instruction · Early childhood · Teacher Professional Development

1 Introduction

As children construct towers with blocks, navigate mazes, and create small-world prototypes with toys in early childhood classrooms, they are unknowingly developing a crucial skill - spatial thinking. Spatial thinking, involving an awareness of space and the ability to solve problems mentally [34], serves as a gateway for young learners to attain advanced educational and occupational credentials in Science, Technology, Engineering and Math (STEM) [41]. Recent meta-analysis [44] emphasizes the importance of early spatial intervention, pointing out that the malleability of spatial skills is more pronounced in younger children (average effect size, Hedges's $g = 0.96$), surpassing the average effect size ($g = 0.47$) observed in the general population [38]. This underscores the substantial impact of early spatial intervention.

Using construction activities to develop spatial thinking is well-researched, and professional development strategies have been developed for teachers [18, 28]. However, not all children exhibit motivation for spatial activities such as construction.

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In a qualitative study in two Dutch schools, Sonneveld et al. [31] noticed that some children do not like construction. They prefer role play and enjoy pretending with toys like small dolls or chairs. To engage children with diverse play preferences, incorporating design and construction assignments tied to storybooks could be more effective [31]. Fleer [13] observes that many children enjoy solving problems for characters in a story. Fleer conjectures that the use of stories aids children in visualizing the context of their creations. Informed by Klapwijk & Stables [24], the inherent inclination of young children to create and shape their world is a fundamental aspect of human nature. Researchers at the University of Surrey in the UK[1] and the University of Canberra in Australia[2] have compiled a list of stories suitable for teaching STEM lessons with a focus on spatial skills. Despite this, there is a gap in research regarding using such stories for creating design and construction assignments aimed at enhancing children's spatial skills.

Storytelling plays a crucial role in early childhood classrooms, and teachers frequently use storytelling in their classrooms [13]. However, it is new for most teachers to utilize stories to engage children in open-ended design tasks. In design education, students quickly learn to generate satisfactory solutions to ill-defined problems [8]. Open-ended design tasks are multifaceted challenges that involve students in exploring diverse solutions, resulting in a wide range of ideas for teachers to interpret [42]. Therefore, teachers need to know how to identify a spatialized design challenge from a story and formulate it in a manner that allows for multiple solutions to provide pupils with open-ended design tasks. They need to be able to notice the presence of spatial thinking during design and understand how different levels of spatial thinking and creativity will influence their pupils' performance. Finally, teachers need to know how they can best support each child. If we want teachers to include spatial design tasks using stories as a starting point to engage more children in spatial activities, we need sound professional development strategies.

Shulman [32] emphasizes the critical importance of teachers possessing various types of knowledge that serve as the foundation for their decision-making in practice. This foundational knowledge includes content knowledge, pedagogical content knowledge, and general pedagogical knowledge, forming interconnected strands that act as intellectual scaffolding for guiding teachers in their professional endeavors. According to a meta-analysis by Sims & Wood [32], key elements essential for successful Professional Development (PD) are: 1) Cultivating teachers' insights, 2) Motivation for change, 3) Development of teaching techniques, and 4) Integration of these changes into teachers' everyday practice. The Japanese Lesson Study approach taken in our study embodies these key elements, keeping teachers' various types of knowledge in mind. Lesson Study has been proven effective in deepening teachers' knowledge of their own pupils [29], enhancing teaching practices [9, 40], and increasing teacher self-efficacy [35].

In response to the need for supporting teachers in integrating and facilitating open-ended spatialized design activities for pupils aged four to six, a PD program was developed in this study in cooperation with a teacher training institute in Ireland. The PD

1 https://earlymaths.org/spatial-books/.

2 https://elsaprogram.com.au/wp-content/uploads/2022/02/STEM-Booklist_Publishing-040518.pdf.

program included an introductory workshop on fostering spatial thinking. It adopted two cycles of the Lesson Study in each classroom, with a final meeting of the teachers’ group to facilitate knowledge sharing. The primary goal is to cultivate teachers’ abilities to develop a design assignment related to a children’s storybook that would provide children opportunities to use spatial reasoning in problem-solving and design. This paper outlines the setup and outcomes of the PD program in terms of teachers’ knowledge of their own pupils, enhancing spatial teaching practices, and self-efficacy in teaching spatial tasks.

2 Literature Review

2.1 Professional Development (PD) Strategies for Teachers

Although various countries worldwide have introduced design and technology education, the focus on developing spatial thinking through open-ended design assignments is relatively new [31, 45–47], emphasizing the necessity to understand better how effective PD can take place. Strategies for PD may vary, including workshops and courses, Instructional Coaching (defined as ‘an observation and feedback cycle in an ongoing instructional situation’ [21]), Teacher Learning Communities (described as ‘teacher learning in a community setting where teachers convene over time to reconsider their existing beliefs and practices’ [6]), and Lesson Study (characterized as ‘observation of live classroom lessons by a group of teachers who collect data on teaching and learning and collaboratively analyze it’ [27].

Although workshop and course-based PD help educators acquire new knowledge, the transition to applying this knowledge in practice often poses a significant challenge. Instructional coaching, a personalized support system aimed at fostering individual growth for educators, is often hindered by its high cost and the potential lack of peer support, given its predominantly one-on-one nature. Therefore, our focus in this paper is on PD strategies that are especially effective in supporting teachers in integrating new teaching techniques into their everyday practice. International review studies [10, 20, 43] underline Lesson Study’s impact on teachers’ knowledge, behavior, attitudes, and its influence on student learning. Lesson Study, originating from Japan, is a structured process focusing on studying pupils’ learning in a live educational setting. Through collaborative efforts, teachers investigate the cognitive processes involved in their students’ learning. At its core, Lesson Study involves the observation of live classroom lessons by a group of teachers who collect data on teaching and learning and collaboratively analyze the findings to drive instructional improvements [9, 26, 27]. Its collaborative nature fosters sustainable professional growth among teachers, with evidence suggesting significant shifts in teachers’ learning patterns [40]. In Lesson Study’s cyclical approach, a particular focus on ‘case pupils’ [9], representing certain learner groups based on their ability or other characteristics is present. All Lesson Study phases involve these case students, which might be a promising strategy to teach teachers to identify and support diverse spatial thinking processes present in a classroom. Lesson Study continuously challenges teachers to anticipate their students’ responses and design lessons to cater to the needs of different ability groups, ideally guided by a facilitator or ‘knowledgeable other’ [36]. Lesson studies, characterized by five ‘big ideas’ [11, 15]: 1) encourage teachers to understand students 2) blend personal and external knowledge 3) research their own practices, 4) engage in collaborative discussions 5) follow a cyclical approach for ongoing improvement.

The outcomes of lesson studies include heightened pedagogical content knowledge [9, 16, 30], improved knowledge of students [29], improved learning patterns of teachers [40], and increase in teachers' self-efficacy [7, 35]. The 'knowledgeable other' role is critical in guiding teachers to incorporate novel pedagogical content. External experts, sometimes also serving as facilitators, bring new knowledge to the group of teachers. For topics unfamiliar to teacher participants, instructional workshops are common to transfer new pedagogical content knowledge before the teachers start designing the research lesson [2, 11]. The collaborative and reflective approach allows teachers to integrate external knowledge into their expertise [11, 36].

Lesson Study's effectiveness in developing various aspects of teachers' professional capacity makes it a valuable form of PD for spatialized design assignments. Earlier, Hawes et al. [18] employed Lesson Study to train teachers in spatializing the math curriculum, and this year-long intervention resulted in enhanced spatial thinking in four to seven-year-olds, including improved 2D mental rotation and visual-spatial geometry. Our study focuses on using Lesson Study to integrate design assignments based on children's storybooks, emphasizing spatial thinking through hands-on activities. The following section will delve into the specific pedagogical content knowledge relevant to our target group.

2.2 Pedagogical Content Knowledge (PCK) for Teachers of Early-Childhood Classrooms in Developing Spatial Design Activities

Many aspects of spatial thinking are integral to children's natural development at home and school. For instance, Yang et al. [44], in a meta-analysis on the effectiveness of spatial skills training in early years, suggested that hands-on exploration, visual prompts, use of spatial language, and spatial gesture training significantly foster young children's spatial skills. Additionally, Cartmill et al. [4], and Kisa et al. [23] recommended that teachers employ spatial language and gestures in their classroom instruction, which proved beneficial in developing spatial thinking for learners aged four to seven years. Research has indicated that construction activities are valuable in the early classroom. Uttal et al. [38], and Hawes et al. [19] suggest various spatially demanding activities, such as copying block constructions, designing number lines with block play, and creating walking paths in the classroom. These tasks should be goal-oriented and guided play to capture the attention of young children. Our focus is on a different type of task: the children are provided with a story and asked to solve a design challenge related to this story. For teachers, it is important to understand how to develop open-ended design tasks that allow for multiple solutions [24] and how prototyping - using sketches and materials to develop solutions - works in the classroom [25].

Design thinking and spatial thinking are related to each other. For example, in a recent study Zhu et al. [45], 37 children aged 11–12 engaged in guided design activity to create tangible data visualizations.

The Irish teachers in our study are not used to such open-ended design tasks, and it is also new for them to foster spatial thinking during design activities. Providing teachers with (external) information and tools to foster spatial thinking is important in this Lesson Study.

2.3 Lesson Study Structure Integrating the PCK Needs of Teachers

A 1.5-h workshop served as a foundational overview, emphasizing the importance of fostering spatial thinking through Science, Technology, Engineering, Art, and Math (STEAM) activities and hands-on design and construction experiences. The content of the workshop included five spatial tools to foster spatial thinking in early childhood classrooms: (1) use of spatial language, (2) use of gestures, (3) use of manipulatives with a "think then do!" approach, facilitating thinking before doing a task, (4) story-based design tasks with construction toys, and finally, (5) the Lesson Study approach to assess case pupils' learning. These elements were regarded as initial steps to incorporate spatial thinking through story-based design in early childhood education, aligning with the key points of the Aistear Framework. In Ireland, Aistear is the curriculum framework (2009) for children aged from birth to six years old. In addition, to provide examples and background information on these five spatial tools the Spatial Reasoning Toolkit developed by The Early Childhood Mathematics Group (ECMG)[3] was introduced [14]. The Toolkit includes posters, videos, guidance, and a learning trajectory from birth to age Seven, showcasing trajectories for key aspects of spatial reasoning: Movement and navigation, Shape properties, and Shape composition and construction. Table 1 below provides an overview of the Lesson Study structure used in our study.

Table 1. The Lesson Study structure for each classroom adapted from Dudley [9]

1	Work shadowing by first author to know the current practices in classrooms.	1 Day
2	Workshop on fostering spatial thinking	1.5 hours
3	Developing the research lesson and selecting case pupils	1 hour
4	Implementing lesson (First Lesson Study Cycle) – including observation and short interview with case pupils	1 hour
5	Post-lesson discussion of teachers and facilitator	30 minutes
6	Second Lesson Study Cycle, implementing adapted lesson	1 hour
7	Second post-lesson discussion	30 minutes
8	Final meeting of 10 participants sharing their learning from Lesson Study	1 hour

Our Central Research Question Is: "What are the outcomes of a Lesson Study approach in supporting Irish early childhood teachers with respect to deepening their knowledge of their pupils, enhancing teaching practices, and impacting teacher self-efficacy, specifically in relation to spatial reasoning during story-based design activities?".

[3] available at: https://earlymaths.org/spatial-reasoning.

3 Method Section

In this first design round, a design-based research approach [39] was applied using a case-study approach to gain in-depth knowledge of the Lesson Study approach. A key element in design research is the creation of an educational innovation that considers the complexity of the context. In our case, we studied the learning processes and outcomes of the participant teachers.

3.1 Participants

Ten teachers from two different Irish schools actively engaged in the Lesson Study cycles. In School A, where the region's schools are relatively small, only two teachers, along with the facilitator (first author), formed a Lesson Study group. Meanwhile, in School B, teachers also worked in pairs, attending the spatial thinking workshop together. During the final post-lesson discussion, all ten teachers convened online for reflection. School A was chosen for practical reasons to assess the effectiveness of the lesson study cycle in facilitating teacher learning in a small school setup. This paper analyzes only the dialogue and classroom instructions from School A: one teacher for junior infants and another for senior infants. Both participating teachers are female, with the senior infant teacher having over ten years of teaching experience and the other with five years of experience. Pseudonyms, Ms. Cassidy, and Ms. Nally have been used in this paper to protect the anonymity of the teachers of Junior Infants and Senior Infants, respectively. Both classrooms had 20 children in each with an age range of four to six years old.

3.2 Data Collection

Data collection occurred during both the facilitated teacher meetings and in classrooms. All teacher meetings and the workshop were audio-recorded. Discussion on lesson plans and adaptations after the post-lesson discussion were collected. The first author and the teachers observed the classroom example pupils and took photos of the intermediate and final designs by the pupils. The first author transcribed the audio data from all sessions. Pupil A, Pupil B, and Pupil C are three case students chosen by classroom teachers, each representing – an expert, developing, and beginner in spatial skills. In identifying the case children as experts, developing, or beginners in spatial skills, teachers relied primarily on their professional judgment. This process was informed by teachers' experiences and beliefs about their pupils and their understanding of what defines spatial design capabilities.

4 Analysis

Kager and colleagues [22] present a conceptual model of continuous professional development through Lesson Study, which systematically explores outcomes and contributing elements for successful PD. Outcomes are defined across various levels: satisfaction and acceptance of PD represent the first level, with subsequent levels focusing on enhancement in knowledge, beliefs, attitudes (level two), change in teaching practice (level three), organizational changes (level four), and sustained enhanced student performance (final level). Our analysis concentrated on outcomes at the second and third levels of the conceptual model. Although the literature on lesson studies presents nuanced categorizations of learning outcomes, we focused on three themes: teachers deepening their knowledge of their pupils [29], enhanced teaching practices and instruction [9, 40], and teacher’s self-efficacy [35]. During the analysis phase, the first and second authors conducted three rounds of categorization, selecting, and comparing sections of conversation highlighting key themes. While we identified more than three categories, we reported on three main themes for our preliminary analysis, focusing on school A. A third researcher external to the research coded the episodes from teachers in school A, with only one episode coded differently. After discussion, it became evident that two themes were intertwined in this episode.

5 Results

The preliminary results of two teachers at School A will be presented here. Both teachers collaboratively developed a lesson plan during the first series of meetings and devised a design assignment related to the story narrating Michael Rosen’s “We’re Going on a Bear Hunt.” Each research lesson began with the teacher narrating the story with attention to spatial words and using gestures. Next, pupils were tasked with creating a trap to capture the bear, initiating with sketching out their ideas and then building it with materials.

Below, we will delineate the episodes representative of the learning that occurred for the following three themes: 1) Deepening Teachers’ Knowledge of Pupils, 2) Change in Teaching Practices and instructional strategies, and 3) Increased Teacher Self-Efficacy. These teachers worked in pairs, with one observing the pupils and how they reacted to the activities during the research lesson.

5.1 Planning the Research Lesson

Before detailing the learning outcomes for teachers, the subsequent planning episode, occurring immediately after the workshop (Step 3 of Table 1), illustrates the evolving thought processes of the two teachers on seeking suitable storybooks and creatively transforming narratives into spatially challenging design tasks.

Episode 1: Post-workshop discussion during lesson planning between teachers

1. *Ms. Cassidy: So, we go with the story (We’re Going on a Bear Hunt Book by Michael Rosen).*
2. *Ms. Nally: Yeah, and then implemented during Aistear. We were doing Little Red Riding Hood, and the brief was to trap the wolves for construction. So, that’s what the construction points are doing.*
3. *Ms. Cassidy: Very good.*
4. *Ms. Nally: But, like in the home corner, they’re making food for grandma at the kitchen.*
5. *Ms. Cassidy: Lovely.*

6. *Ms. Nally: Yeah, and then in arts and crafts, they were designing a map for Little Red Riding Hood's return to grandma's house or to get to the wolf, or whatever they come up with themselves.*
7. *Ms. Cassidy: So, let's just take a story or fairy tale or something, and then we put the brief for each station.*
8. *Ms. Nally: Yeah.*
9. *Ms. Nally: I don't know what story? Is it the Bear Hunt that you're thinking of (to choose)?*
10. *Ms. Cassidy: Yeah, we can use it.*
11. *Ms. Nally: Because there is a lot of [spatial] language when you're reading it with them. That's your language, and you are getting it explicitly, and the gestures acted out and stuff.*
12. *Ms. Cassidy: The language is there, yeah, and getting them to the movements. So, you're given the language of through, over, under. So now we have to give them a task based on the story.*
13. *Ms. Nally: Yeah, a practical one that they solve with design, you know, by making. Can you do something with the cave?*
14. *Ms. Cassidy: Yeah, trap the bear in the cave?*
15. *Ms. Nally: Or the cave is dark, so light up the cave? Or is it hard for junior infant, I suppose.*
16. *Ms. Cassidy: Yeah.*
17. *Ms. Nally: Is there a forest?*
18. *Ms. Cassidy: Yeah, there's a forest, grass, water, and mud that they could pick maybe. So, they pick an area and trap the bear in each different area? So they could decide the area and come up with a trap?*
19. *Ms. Nally: Yeah! A trap based on five different designs.*
20. *Ms. Cassidy: Or even if they were given that freedom kind of which one [area] they choose.*
21. *Ms. Nally: Oh yeah, let them decide the way to set a trap.*

In this episode, Ms. Cassidy selects a book for a design task, aligning objectives with Ms. Nally to incorporate spatial language. Ms. Nally reflects on past projects, emphasizing spatial literacy activities within classroom corners. They deliberate the potential of the chosen book, considering its rich spatial language. Practical challenges, like trapping the bear or illuminating the cave, are discussed, tailored to student developmental levels, as Ms. Nally realized through discussion that "lighting up a cave" would be a difficult task for her pupils. This collaborative process underscores careful planning, highlighting teachers' ability to create effective design tasks based on their knowledge of the class. Finally, pupils were tasked with constructing a bear trap using various materials. Materials included Duplo blocks, Lego, and more. At the end of the lesson, pupils shared their designs, which provided an opportunity for the use of spatial language and gestures. The above episode showcases the value of teacher-developed assignments, leveraging their contextual understanding and enhancing the learning experience for their pupils.

5.2 Teachers' Knowledge of Their Pupils

After formulating the lesson plan, the teachers proceeded to implement it in their respective classrooms, with one teacher actively teaching while the other observed the identified case pupils using an observation sheet. The observation sheet included five tools aimed at fostering spatial thinking in the early childhood classroom, derived from the workshop, enabling teachers to observe students' use of spatial language, gestures, and progress in design tasks. The observing teacher utilized this sheet for post-lesson discussions. In the subsequent post-lesson discussion detailed below, the teachers engaged in a dialogue, focusing on their observations of the case students, with special attention given to their pupils labeled as C, the pupils they expected to have a beginner-level spatial ability.

1. *Ms. Cassidy: Pupil C [beginner spatial ability], I was really surprised of what he came up with. He was actually fantastic.*
2. *Ms. Nally: The imagination is [fantastic]*
3. *Ms. Cassidy: Yeah*
4. *Ms. Nally: I was just wondering if he'd be on task or not, that was my [Pupil] C.*
5. *Ms. Cassidy: and that was the same with my child C. It is the same thing that I didn't think that he'd do but it is actually the interest was there.*
6. *Ms. Nally: Yeah [interest] of what they were doing was there*
7. *Ms. Cassidy: Yeah and then that kept them focused. just that he had an interest in the topic and then he use his imagination and that kept him on task*
8. *Ms. Nally: Yes absolutely*
9. *Ms. Cassidy: But it is so interesting that these children that we picked that they will go off task were the ones that actually did best*
10. *Ms. Nally: Surprised us.*
11. *Ms. Cassidy: Yeah absolutely.*

Both teachers express surprise at the performance of a case pupil C, initially placed in the beginner spatial ability group, noting the pupil's remarkable imagination. They had doubted whether beginner pupils, denoted by the letter C, would stay on task but were pleasantly surprised to find them motivated and engaged. The senior infant teacher links this motivation to the pupil's interest in the topic and ability to utilize imagination, which ultimately led to their success. This discovery challenges the teachers' initial expectations and highlights the importance of recognizing and nurturing students' individual qualities. Despite initial reservations, the story framework effectively engaged beginner spatial ability pupils. While expert and developing spatial ability pupils performed as expected, one junior infant pupil perceived as expert spatial ability by teachers initially showed limited spatial language use, possibly due to shyness during observation. However, upon repeating the lesson, the pupil demonstrated satisfactory spatial language skills.

In the following episode, Ms. Cassidy, who observed the lesson, shared insights from her interview with Pupil C during his design task during the post-lesson discussion.

1. *Ms. Cassidy: When I went over to him [pupil C], he said, "I'm drawing a map," and he said, "I did instructions for it."*
2. *Ms. Nally: Yeah.*
3. *Ms. Cassidy: So, he was even talking about his design [sketch]. He was using a lot of spatial language, like that the trap will go over the bear when you put it out there; it will be a cage, he will get squashed down, these [areas] have to be covered, this is the way to slam [the cage gate], and he was moving on the different parts.*
4. *Ms. Nally: Yeah! There was a part at the top that was moving up and down.*

5. *Ms. Cassidy: Yeah, so he was very [involved]. Then he explained the wheel that they spin and these are the cutters, and when the bear breaks out… so we really had a lot of thoughts on what he was doing, and then he was talking about the wacker goes up and down, up and down, then he put a camera on it as well, and it goes in there and talks about … he [actually] made a bear.*
6. *Ms. Nally: And he showed us.*
7. *Ms. Cassidy: Yeah, and how the bear would go in here, and then they get trapped.*
8. *Ms. Cassidy: Yeah, so really engaged, really good spatial thinking, and that was your pupil C.*
9. *Ms. Nally: Yeah! [Laughs with surprise].*

Here the observing teacher shares insights she got from interviewing beginner ability Pupil C, who had surprised both teachers with technical details and spatial language use while describing his design. Sentence 3 captures the specific instance where Pupil C not only described his design but used advanced technical terms like "instructions" and considered the design as a "map," showcasing some understanding of the spatial elements. Sentences 3–6 show how Pupil C adeptly used spatial language to describe the intricate details of the trap's functionality, showcasing a higher level of spatial thinking than perceived by the teachers as he relates the form to the function of the design. This discussion between teachers shows how Lesson Study can deepen teachers' knowledge of pupils and they are also learning how a child can bring spatial language and technical understanding to a design process. The combination of having to predict how the case pupil will behave, observing the actual behavior, using during-class interviews and a reflection (Step 5, Table 1.) together led to deepened knowledge of pupils during a spatialized design assignment.

5.3 Change in Teaching Practices and Instructional Strategies for Spatialized Design Activities

In the post-lesson discussion following the initial lessons in both Junior and Senior Infant classes (Step 5, Table 1), teachers reflect on various activities. The selected episode captures the point where teachers begin to recognizing the instructional potential inherent in utilizing sketches as reference points.

1. *Ms. Nally: I think I'm gonna leave my sketches with my children so that they can refer to it whenever they're building their traps.*
2. *Ms. Cassidy: yeah!*
3. *Ms. Nally: Because I just thought last time some of them were talking about their sketch and wanted to show me their design, but I had already collected it.*
4. *Ms. Cassidy: Yeah.*
5. *Ms. Nally: So, I think I will leave it on their table to refer back.*
6. *Ms. Cassidy: Yeah, the sketches were good just for that you know they think then do they definitely…*
7. *Ms. Nally: yeah, …give them time to think about what they want their design to look like.*
8. *Ms. Cassidy: yeah.*

In this exchange, Ms. Nally initiates the conversation by expressing her intention to leave sketches with the children based on her reflection from the previous lesson (sentences 1 to 5). Ms. Cassidy agrees, emphasizing the importance of allowing children time to think about their designs (sentence 7). The teachers collectively recognize the value of sketches in aiding children's memory and understanding of their design tasks. Ms. Cassidy agreed and added that leaving sketches with children also matches one of the five tools they learned during the workshop, which is "think then do" (sentence 6).

The teachers implement this change in a later lesson (step 6, Table 1). In the post-lesson discussion (step 7, Table 1) that follows the implementation of leaving sketches with the children, teachers explore the impact of this instructional shift on pupils' use of spatial reasoning.

1. *Ms. Cassidy: Sketch!*
2. *Ms. Nally: Yeah, sketch. I left the sketches on their tables, and some of them used it in their actual design, which I thought was good.*
3. *Ms. Cassidy: A lot of them did. And some built on top of their sketches, putting some pieces on it.*
4. *Ms. Nally: Some referred back to their sketch, saying, "This is the tree I built."*
5. *Ms. Cassidy: Yeah! They were describing it.*
6. *Ms. Nally: Yeah! That's why I think it was a good change as well.*
7. *Ms. Cassidy: I think it was interesting. One of them, the child had drawn like a door and a keyhole and a key, and then she had, when she showed me everything, yeah, in her Lego she had the keyhole and key and all.*
8. *Ms. Nally: Yeah, yeah, so they were referring back afterwards. I didn't take up the sketches last time, but I think it was a good idea to leave them with them.*
9. *Ms. Cassidy: And Child C in your room, he was saying, "Look, they look exactly the same," you know.*
10. *Ms. Nally: Yeah.*
11. *Ms. Cassidy: And he kept going back to the sketch.*
12. *Ms. Nally: Yeah, it's so interesting to see.*

In this exchange, Ms. Cassidy initiates the conversation with the exclamation "Sketch!" as an important change in their lesson plan. Ms. Nally observed that leaving the sketches on the children's tables had a beneficial impact on their engagement and design process (sentences 2 to 6). An anecdote about Pupil C highlights the significance of providing students with a reference point, as he recognizes the similarity between his sketch and the actual design (sentences 9 to 11). This example about sketches shows how, through Lesson Study, teachers are changing instructional strategies for spatialized design activities. Although the practice of keeping sketches available during 3D prototyping is generally known in design and technology education [12], these teachers who are novices in design education discover the value of this practice and are motivated to implement this change. Teachers implemented additional changes, such as excluding open-ended materials like straws, toilet rolls, and cardboard from junior infant classes. Instead, they emphasized the use of Legos, as they found cutting and folding activities challenging for younger pupils. They showcased various designs made by pupils, encouraging the use of spatial language. Following the Lesson Study, they discussed adjustments to pupil grouping, aiming for natural collaboration, such as during Aistear time. Ms. Nally utilized cosmic yoga from YouTube to engage students, with a focus on spatial language.

5.4 Increased Teacher Self-Efficacy

In the subsequent teacher dialogue, during the final reflection on the Lesson Study cycle (Step 8, Table 1.), Ms. Nally and Ms. Cassidy reflect on their learning. They offer insights into the teachers' increasing confidence and efficacy in integrating spatial thinking into their regular teaching practices.

1. *Ms. Nally: Overall, we are more aware of the importance of developing spatial thinking, especially in the early years of school. We've also become aware of the link between a deep understanding of spatial language in the early years and spatial ability later in life.*
2. *Ms. Cassidy: We realized the importance of using gestures to enable a deeper understanding of spatial language. We've also recognized the significance of using a story stimulus to help embed memory, particularly episodic memories. We find the spatial thinking development toolkit useful as it shows opportunities to include spatial language in daily teaching. Going forward, we plan to use the five spatial tools for fostering spatial thinking in lessons. This involves incorporating more design and make tasks in our Aistear (early childhood framework in Ireland) and linking them to a story stimulus. We will continue to use gestures in our teaching practice, as it is something we already do frequently, whether giving instructions for teaching letters or numbers, showing direction, or engaging in poem songs and nursery rhymes. We'll also continue to reflect on the children's learning.*

In the final reflection on their learning, Ms. Nally and Ms. Cassidy highlight their increased awareness of spatial thinking's importance, emphasizing its connection to later-life spatial ability. They recognize the value of gestures and story stimuli, planning to integrate these elements into lessons. Miss Cassidy mentions, "We've also realized the importance of using a story stimulus to help embed memory," indicating their intention to utilize these techniques. As they discuss plans to incorporate design tasks within the Aistear framework, this conversation reveals their growing confidence in integrating "five spatial tools" given to them during the workshop, offering insights into their efficacy in seamlessly incorporating spatial thinking into regular teaching practices.

6 Discussion and Conclusion

Our aim was to study the outcomes of a Lesson Study approach and how it may deepen teachers' knowledge of their pupils, teaching practices, and its impact on teacher self-efficacy, specifically in relation to spatial reasoning during story-based design activities.

Preliminary results indicate that teacher learning occurred on each of the three selected themes. Teachers' knowledge of their pupils increased. Through case pupil selection, teachers gained insights into beginner pupils' spatial thinking, challenging pre-conceived notions and prompting shifts in beliefs about beginner pupils' abilities and how to engage such pupils in design tasks. Furthermore, enhancement in teaching practices was evident. Teachers' use of sketches to aid memory and communication aligned with workshop themes for effective spatial learning. Teachers also implemented five spatial tools, including spatial language and gesturing, and through reflection, changed and improved these teaching and instruction practices. Although these improvements are subjective, driven by teachers' experiences, imagination, and their interpretations of external information, they are a worthwhile step toward spatialized design assignments. The results also show the teachers' creativity in crafting assignments from storybooks, showcasing their ability to include design-based spatialized activities. Although the episodes on developing design assignments do not conclusively determine if teachers acquired new skills or already possessed them, the focus on spatial elements within storytelling is evidently new. Finally, some increase in teacher self-efficacy has been noted in the final meeting of teachers. Their plans to continue with spatialized design assignments and the use of five tools for fostering spatial thinking indicate possible sustainability. Compared to earlier PDs done in spatial thinking integration in classrooms [18, 28], one of the biggest barriers has been the time constraints from the side of participating teachers in long interventions for incorporating required instructional changes for fostering spatial thinking [3]. Our preliminary results suggest that the lesson study processes implemented in our study may motivate teachers to integrate spatial thinking into their classrooms while they are still working on their curriculum.

Further analysis of outcomes in school B is ongoing, which will provide additional insights. Future investigations will also delve into mechanisms of lesson study contributing to these outcomes, such as the workshop's alignment with participants' personal knowledge and the effectiveness of five spatial tools and observations in enhancing teacher self-efficacy. While the generalizability of findings requires careful consideration, they lay a foundation for empowering teachers to effectively support children with diverse spatial abilities in early childhood education.

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