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ORIGINAL PAPER

Science learning in 3- and 5-year-old children in the same free-choice learning environment on plant diversity

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Abstract

This study responds to the need to produce inviting learning environments that help to build intentional science learning in early childhood education. We present a free-choice science learning environment on plant diversity in the fall. From the moment it was implemented, we analyzed whether children of different educational levels acted in accordance with the objectives put forth in each activity of the environment when they are given free choice. We also explored the potential relationship between achieving the stated objectives and social interactions. The participants were 13 three-year-old children and 14 five-year-old children. The free-choice sessions were video recorded and supplemented with notes taken by three researchers in a field notebook. From the records, we categorized the data according to the actions we expected of the children in each activity, related to how they interacted with the materials and the social interactions that emerged. The results show the influence of social and material interactions, as well as the children's previous knowledge, in attaining the objectives laid out in the design. Based on these results, we propose some principles and guidelines for designing, implementing and evaluating these learning environments in early childhood education, as well as future lines of research.

Keywords Comparative study · Design-based research · Early childhood education · Free-choice learning · Observational strategies · Plants · Science education

Introduction

Learning environments can be understood as physical spaces with specific characteristics in which, using different methodological strategies or the utilization of specific resources or materials, students can interact and communicate with their peers, teachers, or other stakeholders. In this way, the aim is to contribute to the students' learning and social development (García-Rodríguez et al., 2023). During early childhood education, the production of stimulating learning environments is especially important in science learning, because it helps to build intentional science learning (Fleer et al., 2014). In order to do so, there are three elements that need to be considered:

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1. Firstly, in the field of science education, there has been a trend that stresses the need to start tackling science education from the earliest years of school (Worth, 2020). During these early years, children learn mostly via perception, supported by their senses and specific daily experiences. Direct sensory experience is the starting point for scientific observation and helps children to give meaning to the world around them (Anderson, 2015).
2. Secondly, interacting with the natural environment and the great variety of sensory input in the environment can help children of all ages to learn content related to the natural sciences and develop scientific skills and attitudes (Earle, 2022). In fact, some studies conducted at this stage demonstrate how children between the ages of three and six can show rather sophisticated scientific thinking and participate in scientific practices of a certain complexity (Jirout & Zimmerman, 2015; Monteira et al., 2022).
3. Thirdly, another important part of early childhood education is the development of autonomy. Providing a time and a space for children to explore and play freely, supported by teachers, helps them to develop autonomy and possibly interests in certain subjects (Barrable, 2020). The cultivation of free-choice learning environments, in which children can choose when, where, what and with whom to learn, helps to develop their autonomy as it produces situations that involve identifying the learning options offered and choosing one of them to satisfy their interests and meet their needs (Bamberger & Tal, 2007).

However, transforming the physical space of a classroom or a school does not always create a learning environment. To make this transformation effective, we must consider the social and material interactions taking place in the physical space over time (Kokko & Hirsto, 2021). Starting from this basis, the alignment of these aspects and the efforts to integrate them have created a fertile ground for different types of methodologies focused on teaching science, such as free-choice science learning environments (FSLEs), which are the main focus of this study.

Though FSLEs are hardly new to science education, they have primarily focused on informal contexts like museums, libraries and zoos (Bamberger & Tal, 2007; Haldón Lahilla et al., 2022; Huang et al., 2019). However, the connections between formal and informal spheres have culminated in the search for a 'third space' to integrate spheres built through free-choice activities (Dunlop et al., 2019), which has led to the expansion of free choice to formal education.

However, studies of science in formal early childhood education that focus on free-choice learning are scant. For example, Nayfiel et al. (2011) evaluated the science learning of children in free-choice moments focused on the use of specific materials and the teacher's role, while Mateo and Sáez-Bondía (2022) assessed a single-subject free-choice learning environment on minerals, focusing on the science learning of children and how their social interactions influence it. Peinado et al. (2022) introduced an FSLE in the school playground and analyzed its effects on the actions of early childhood education students. These results shed light on the importance of choosing and arranging the materials used in the different activities included in the space, of the children's previous knowledge and of the role of the interactions during free choice.

Due to the importance of choosing and arranging the materials and the efforts involved in designing the activities provided in these environments so that they encourage free experimentation by children (Mateo & Sáez-Bondía, 2022), we wonder if it is possible to use an FSLE with different age groups. Therefore, framed as design-based research (hereinafter, DBR; Anderson & Shattuck, 2012), this study aimed to design and evaluate an FSLE on plant diversity for groups of children of three and five years old. The objective of this study was to analyze whether the design of the activities included in the FSLE encourages children of different education stages to take the actions for which they were conceived. To accomplish this, we took social and material interactions into account. Therefore, the questions that arise include:

- Which objectives intended for each activity in the FSLE were achieved? What differences were observed according to the age group studied?
- What kinds of social interactions occurred? What role did they play in achieving the objectives? What differences were observed according to the age group studied?

Conceptual framework

We understand FSLEs as spaces laid out with activities prepared mostly with natural materials and arranged by science-related subject areas (living beings and their environment, air, light, minerals, etc.). They are learning environments that foster well-being, communication, research, modeling, experimentation, inclusion and high emotional impact and aim to reflect children's and teachers' interests. The activities designed (e.g., an area where ramps can be arranged at different heights and with surfaces of different degrees of roughness) are attractively and suggestively located in the physical space, thus promoting free access to children for the purpose of learning about science (Pedreira et al., 2019).

The design of these learning environments takes into consideration both the space and its layout (furniture, lighting, arrangement of the activities, etc.), since they are factors determining the achievement of educational objectives (Laorden & Pérez, 2002). Therefore, teachers must think about and plan the layout of the space (Brooks, 2011; Kokko & Hirsto, 2021). They must start to consider how to organize and structure it well enough to enrich it and make it a source of stimulation for the activity, reflecting the intentions and meeting the needs of teachers and students alike.

It is also true that a classroom's spatial conditions are associated with certain psychological, emotional and behavioral barriers (Ares Nicolás, 2021) and, yet, the fact that this type of barriers exists cannot be the main factor deciding teachers' educational approaches, just as criteria like spatial organization or layout cannot be allowed to determine teaching practices. In this regard, the literature contains studies by Mateo, Cisneros et al. (2020a), Mateo, Ferrer et al. (2020b) and Mateo and Sáez-Bondía (2022) that provide evidence of how the educational space can be transformed in small ways to adapt it to the educational and methodological requirements of certain educational strategies. These transformations are achieved with simple, low-cost, attractive materials that structure and reorder the space and are easily assembled and disassembled without needing to become a permanent fixture in the classroom.

Not only are the spatial organization and layout important, but the materials to be used in the FSLE must be selected with the utmost diligence and care (Brooks, 2011). We recommend the use of safe, natural, everyday and long-lasting materials suitable for working on scientific content and of instruments such as magnifying glasses, magnets, scales and so on. They should be arranged in a way that encourages children to interact with them directly so that they can experiment, explain their ideas or trigger their development (Pedreira & Márquez, 2019). In other words, the activities contained in the FSLE should have materials appropriate enough for the children to perform science-related activities such as observing, comparing, describing or identifying causal relationships in the context of certain phenomena and subjects of experimental sciences, like friction forces, the properties of minerals and homogeneous mixtures. The aim is to produce what Fleer et al. (2014) call "opportunities for incidental science learning".

Therefore, the intention of any given FSLE must be borne in mind when designing its activities (Pedreira & Márquez, 2019). The aims pursued in each activity should be established, as should the types of actions that the children are expected to take. Thus, as described in the context of the study, the activities should be designed to connect the scientific content with the development of basic scientific skills (observing, comparing/identifying, classifying, measuring or communicating), like those suggested by Jirout and Zimmerman (2015).

In this way, the FSLE aims to encourage children to have a direct experience with certain phenomena or objects related to science. By doing so, children can make their scientific ideas explicit and make them evolve while working without instruction. The key element of the FSLE is the fact that children can go wherever they want, with whomever they want and for as long as they want (Pedreira & Márquez, 2019). That is, in the moments of free experimentation at FSLE, children are free to choose activities, actions and interactions with materials, peers and adults.

Regarding the evaluation of learning environments similar to FSLE, Andre et al. (2017) consider social interaction (with peers and with adults), technological interaction and interaction with the materials, as well as the relationships among them. This study focused on how children interact with the materials in the arrangement intended during periods when they work freely. Social interactions are also considered, since they dominate during free-choice time (Shaby et al., 2019). Since FSLEs seek out incidental opportunities to learn science, the teacher's role is not to tell the children what they should do, but rather to intervene without interfering with the children's stated or unstated demands (Hsin & Wu, 2011).

Designing, implementing and evaluating FSLEs requires investigative approaches that can produce contextual knowledge about their design and its implications, bearing in mind how they are conducted in classrooms in formal contexts. These approaches fit DBR like a glove. DBR involves cooperation between researchers and teachers so that the needs are identified, the literature is reviewed and the program is designed, carried out and evaluated, generating contextualized theoretical design principles (Anderson & Shattuck, 2012). It also brings a mixed perspective to research that includes both quantitative and qualitative approaches (Andre et al., 2017).

Methodology

Context of study

Educational needs

The study was performed in an early childhood and primary education center in Spain with a long history of collaboration between teachers and researchers. We focused on three- and five-year-old groups of children attending early childhood education. The year before, the teachers had worked with an FSLE at the end of a project, so they were interested in working with these learning environments to tackle a common subject in October from a different perspective: the fall. The staff agreed to design an FSLE on ‘plant diversity in the fall’ for both groups, trying to adapt it to the intentional scientific skill requirements of each.

Design of a free-choice science learning environment on plant diversity

As the teachers and researchers agreed, the FSLE was designed in three structured stages: (1) agreement on the scientific ideas on plant diversity on which they wanted to work and adapted to early childhood education; (2) insertion of those ideas in the FSLE activities, producing an intentional arrangement of the materials that would help the children to work on certain scientific skills (combining these first two stages led to the objectives intended in each of the activities, Table 1) and (3) arrangement of the materials within the activities and the physical classroom space.

The ideas on plant diversity included simple descriptive content related to the fall, such as:

(1) Leaves, fruits and seeds have structures that cannot be seen at first glance (villi, pores and others), related to activity 2 (hereinafter, A2).
(2) In the fall, we can observe different-colored leaves (A3).
(3) Pine cones come in different shapes and sizes (A4).
(4) There is a great diversity of leaves distinguishable by their shapes (acicular, palmate, etc.), their edges (smooth, serrated) and the arrangement of their nerves (A5 and A6).
(5) Nuts are different with and without the shell (A7).
(6) The wind moves different fruits unequally according to their shape (elm, China soap tree) (A8).

Once these ideas were defined, we considered the number of activities to be incorporated, the materials and their arrangement to encourage the children to take certain actions related to developing scientific skills, as shown in Fig. 1 and Table 1. During this process, attention was paid to the fact that, in early childhood education, it is advisable to

Table 1 Activities that make up the “Fall” *FSLE* and objectives of each

Activities (P)	Objective
(A1) Library	Observe images related to the fall and read words or short texts
(A2) Magnifier	Use a magnifying glass to encourage the observation of details invisible to the naked eye in the materials used
(A3) Colors	Observe, compare and identify leaves by color
(A4) Touch	Use touch to learn about different types of pinecones, describe their characteristics and identify them with the photos
(A5) Leaves	Observe and compare different shapes, edges and veins of the leaves and identify them with the photos
(A6) Draw	Observe and compare different shapes and sizes of leaves Draw an outline of the leaves (5 years old) Identify the outline with the leaf (3 years old)
(A7) Seeds and nuts	Observe and compare different nuts and identify them with and without the shell
(A8) Wind	Generate wind using different materials Observe and compare the movement of different seeds and nuts when wind is generated

Fig. 1 Activities and materials incorporated in the FSLE

work on variables one by one (Dejonckheere et al., 2016). Yet, this is not always possible when using natural objects. For example, A4 included pine cones of different coniferous species together with some photographs of them. The children had to touch different pine cones (but always pine cones) to select them and identify them with the photos. However, although the A5 leaves were supposed to be of a similar color (different shapes, same color), differences were noted because they were of different species.

One thing to consider based on how the activities were designed is the introduction of a 'surprise' element (Pedreira et al., 2019) related to each variable in the activity (leaf color, for example) that makes the children question why it was added. For example, A3 included an artificial leaf colored differently than a natural leaf.

Another activity (A1) incorporated stories and books related to plant diversity where they could look for and read words and simple texts. Finally, the teachers and researchers agreed that the differences in fine motor skills and writing ability of three- and five-year-old children called for different approaches to both groups in A6. The three-year-old children were given the shape of leaves on kraft paper and encouraged to make associations and compare, while the five-year-old children were provided materials and encouraged to sketch the outline of the leaves and compare. As a result, one of the objectives of this activity was different for each group (Table 1).

Finally, considering the spatial features of the classroom where the FSLE was to be implemented, the activities were arranged to be accessible and seamless enough for use during free-choice periods (Fig. 2).

The participating children

The designed FSLE was used for a group of 13 three-year-old children in the first year of early childhood education and another group of 14 five-year-old children in the third year of early childhood education. The three-year-old children were in their first year at the school and were very calm, with long attention spans. They had high group cohesion and depended on an adult to start games and tasks. Most of the five-year-old children had already attended the school in previous years and were used to developing the scientific skills typical of this stage, having already done projects with living beings and materials, but they had no experience with FSLEs. This group was highly diverse, showing varying levels of autonomy and development. The particular characteristics of both groups (level of autonomy vs. diversity) made the FSLE approach an ideal point of departure for creating common interests in the classroom.

Implementation during free-choice periods

As stated above, this study evaluated the design and implementation of the FSLE during free-choice periods. In these periods, the children worked freely and autonomously. They were free to move around the built learning environment, they could interact with the materials, their peers and teachers and, thus mobilize their scientific knowledge and skills. However, we think it is important to point out that, after the free-choice period, the

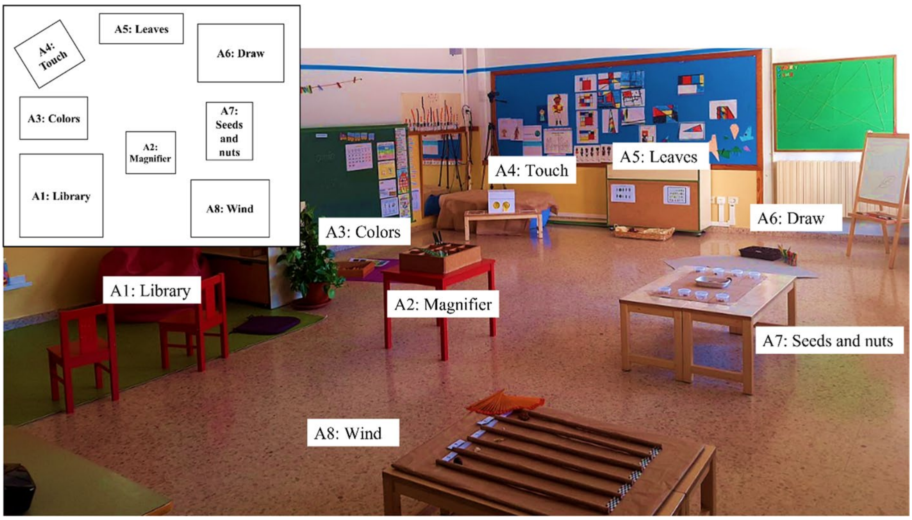

Fig. 2 Arrangement of the activities

teachers led more guided activities to work on what had been tackled in more detail, using the activities contained in the space.

The FSLE was designed to take place in the same physical space (Fig. 2) in which the three- and five-year-old groups worked freely at different times. Before starting the FSLE, both groups were told that they could go wherever and with whomever they wanted for as long as they liked. Their only instruction was to respect the materials and their classmates. Although these spaces are characterized in part by a flexible use of time, given the teachers' previous experience, they agreed that the children would work freely for approximately 30 min. In the end, the five-year-old group worked freely for 30 min and the three-year-old group did so for 35 min.

The role of the adults during the free-choice periods was focused on 'intervening without interfering' in response to the children's demands. The teachers did not try to give a direct answer to these demands, but rather to provide guidance. For example, if a child tried to identify nuts inside and outside the shell, an adult who was watching could ask the child what they he had noticed to identify them.

Data collection

From the perspective of DBR, this study employed strategies consistent with observational data collection methodology (Portell et al., 2015). Specifically, it used observational records and pre-established observational criteria to match the objectives of the activities of the designed FSLE. As such, the following data collection tools were used: (1) four video cameras arranged in the classroom to capture the children's verbal and non-verbal actions during the four activities and how they moved around between them and (2) a field notebook in which three researchers wrote down what they observed regarding the children's actions during the free-choice periods.

Data analysis

Taking the intended objectives in each activity as a reference (Table 1), two researchers viewed the video recordings of both groups independently. For each of the eight activities, they counted the number of children in attendance and the number of children who took actions that indicated that they were doing what was expected. The researchers also took note of the indicators to evaluate each action. For example, the objective of A2 was to observe structures in detail with a magnifying glass. If a child picked up the magnifying glass and one sample, looked through it and/or even verbalized something (such as "how big"), this was considered an indicator of having achieved the objective. However, if the child only held the magnifying glass for a few seconds and looked at it without focusing, the objective was not considered to have been attained. The types of social interactions that took place in each activity were also noted. Specifically, consideration was given to whether the children's interactions with their peers were linked to sharing what they had discovered or if they focused solely on what another classmate was doing, often repeating the same action taken by that child. Interactions with adults were evaluated if findings were exchanged or if the teacher told them about using the material. Finally, the researchers checked notes made in the field notebook about unexpected findings that could be of interest to how the FSLE worked during free-choice periods (like the movement of materials from one activity to another, for example).

Following the analysis, the data obtained by each researcher were compared and the existing concordance was evaluated using Cohen's Kappa coefficient (Cohen, 1960), obtaining optimal values (Kappa = 0.870 $p < 0.05$ with an agreement rate of 93.7%). The existing discrepancies were evaluated and agreement was reached. The data obtained were grouped by age for interpretation. Consideration was given to: (1) the relative frequency of the children's attendance to each activity, (2) the relative frequency at which a child achieved the objective based on the number of children in attendance and (3) the relative frequency of interactions per child/adult initiating them, bearing in mind the total number of children attending the activity and how it compares to the average objective achievement rate. To establish comparative value, the activity was generally considered successful if over 70% of the children in attendance took actions related to the intended objectives.

Findings

Intended objectives achieved and differences between groups

To find out the extent to which the studied groups took actions linked with the objectives set out in each activity, the first step was to discover the number of children per group who worked on each of them. As shown in Table 2 (Attendance), over 70% of the children in both the three-year-old group and the five-year-old group worked on the

Table 2 Number of children who took actions related to the objectives of each activity of the Fall learning environment (objectives met by more than 70% of the children are marked in bold if attendance is above 70%)

Activities	Intended objectives	3 years old ($n = 13$ children)		5 years old ($n = 14$ children)	
		Attendance	Achievement	Attendance	Achievement
A1. Library	Observe images and texts	13 (100%)	**11 (84.6%)**	13 (92.9%)	**13 (100%)**
A2. Magnifier	Use a magnifying glass	12 (92.3%)	5 (41.7%)	13 (92.9%)	**12 (92.3%)**
A3. Colors	Observe	2 (15.4%)	0	7 (50%)	6 (85.7%)
	Compare and identify leaf and color		0		3 (42.9%)
A4. Touch	Use touch	10 (76.9%)	**7 (70%)**	14 (100%)	**14 (100%)**
	Identify pinecones and photos		3 (30%)		**11 (78.6%)**
	Describe pinecones		0		**10 (71.4%)**
A5. Leaves	Observe	1 (7.7%)	1 (100%)	3 (21.4%)	2 (66.7%)
	Identify		1 (100%)		0
A6. Draw	Observe	10 (76.9%)	3 (30%)	11 (78.6%)	**9 (81.8%)**
	Compare		3 (30%)		4 (36.3%)
	Draw		–		**9 (81.8%)**
A7. Seeds and nuts	Observe	13 (100%)	4 (30.8%)	10 (71.42%)	**9 (90%)**
	Identify		0		6 (60%)
A8. Wind	Generate wind	10 (76.9%)	**10 (100%)**	11 (78.6%)	**8 (72.7%)**
	Move seeds in the wind		4 (40%)		**9 (81.8%)**
	Compare movements		2 (20%)		**8 (72.7%)**

activities independently and took actions in them all, regardless of whether they matched the intended objectives. Only A3 and A5 were 'less successful' activities.

There were marked differences in how the actions taken by the three- and five-year-old children matched what was expected in the activities (Table 2, Achievement). Over 70% of the children in the five-year-old group took actions related to one of the objectives in every activity, except in A5; given its low frequency, generalizations cannot be made about the group's potential achievement of its objectives. On the other hand, the three-year-old children attained one of the objectives in A1, A4 and A8.

Therefore, the objectives reached by the five-year-old group are associated with observational skills and the use of the senses regarding the different materials provided (A1, A2, A4 and A7; Table 2). The intended objectives that were not achieved relate to actions like comparing/identifying, using a color scale, and then comparing (A3), comparing leaf shapes after drawing them (A6) and identifying nuts with and without the shell (A7). Actions related to science learning not initially proposed were also noted, such as describing the leaves observed in A5 (*They have stripes*) or identifying some nuts in A7 (*It's a nut*). There was also a tendency to transfer the knowledge acquired, because they moved from the magnifying glass (A2) and instruments to generate wind (A8) to other activities, carefully observing the new materials or noticing the effects that they generated. However, unexpected actions were also detected, resulting from the introduction of certain materials to the activities like in A6, where colored paints were provided and the children ended up painting with colors not found in what they had observed (shades of pink, blue, etc.) without stopping to observe or compare the shapes or edges of the leaves.

More than 70% of the children in the three-year-old group achieved the intended objectives of three of the eight activities; these were related to using familiar materials like books (A1), sense-based actions such as touching (A4) and phenomena that they had experienced previously, like generating wind (A8). Because only one three-year-old boy and one three-year-old girl attended A3 and A5, respectively, no generalizations can be made about the potential achievement of their objectives. Unexpected actions had no link to scientific knowledge that might have expanded the range of possible objectives to consider in the activities and were related to symbolic play. For example, the children used the magnifying glass to look at their fingerprints in A2.

Role of interaction in achieving the objectives and the differences between the groups

The design and implementation of the *Fall* FSLE led to interactions between peers and with adults in both age groups. Still, there were differences between the groups: (1) the number of interactions was proportionally higher in the five-year-old group and (2) distinct types of interactions were more dominant in each group. Whereas five-year-old children interacted with their classmates by sharing findings (verbally or non-verbally), the three-year-old children watched what their peers were doing and imitated them afterwards. A vicarious way of learning not linked to achieving the objectives was more dominant in this group (Fig. 3). The five-year-old children interacted with their peers to share findings in all the activities. Notable in this regard were A1 ($n=9/13$, 69%), A4 (n = 9/14, 64.3%) and A6 ($n=6/11$, 54.5%), which were also the most attended activities and the ones whose objectives were achieved by the highest proportion of children. In contrast, although most children attended A2 and A8, they had a lower proportion of these types of interactions ($n=5/13$, 35.5% and $n=1/11$, 9.1%, respectively).

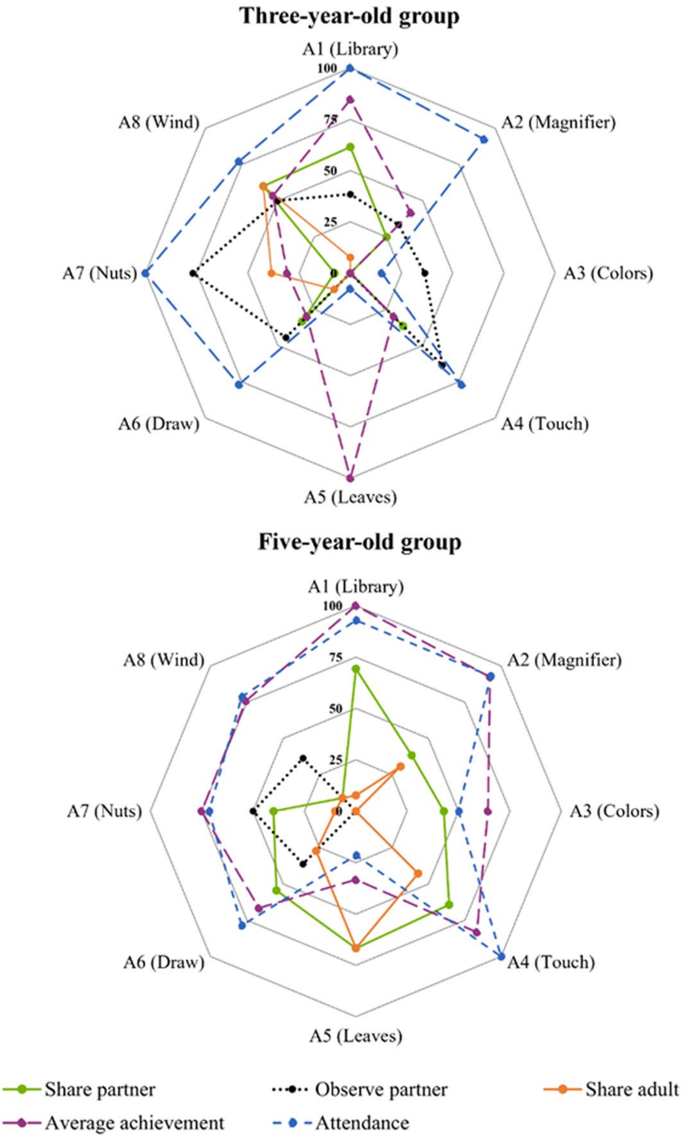

Fig. 3 Percentage of children who interacted with their peers (by sharing or observing) and with adults, attendance and average achievement of each activity's objectives for each age group

Interactions focused on watching other classmates were seen in activities in which the children knew little about the objectives or the materials. This was the case when comparing shapes in A6 ($n=4/11$, 36.3%), when trying to identify nuts in A7 ($n=5/10$, 50%) and when watching other children use air pumps and then comparing the movements in A8 ($n=4/11$, 36.4%) (Fig. 4). Many of these interactions arose from the need to clarify ideas related to skills like comparing and identifying.

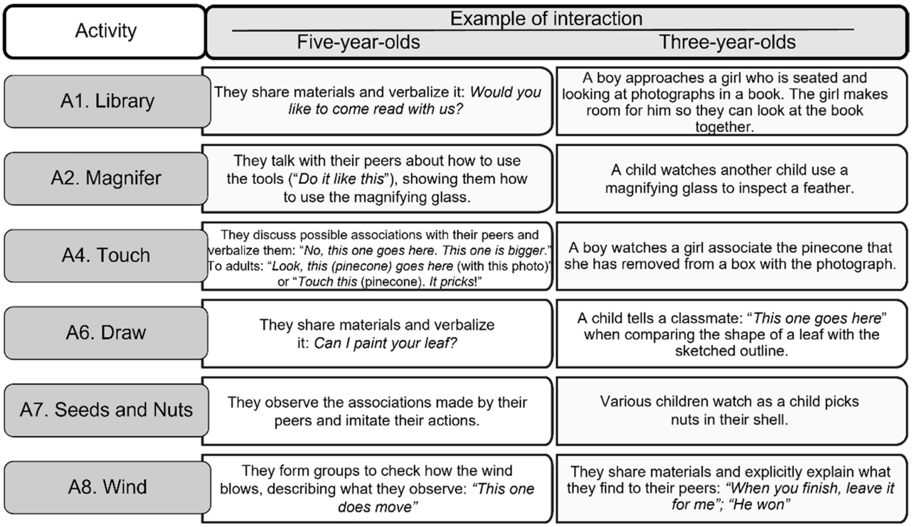

Fig. 4 Examples of interactions in the most attended activities

Interactions with adults essentially hinged on the children talking about findings related to what drew their attention or implicitly asking if they identified things correctly, as occurred in A2 ($n=4/13$, 30.8%) and A4 ($n=6/14$, 42.9%).

The three-year-old children interacted with their peers in six of the eight activities and less often than the five-year-old children did (Fig. 3). The exceptions were in A1 ($n=8/13$, 61.5%) in which they showed each other images found in books, and in A8 ($n=6/10$, 60%) in which they shared materials to generate wind (Fig. 4). Notably, these activities with more peer-to-peer interaction correlated with activities in which the children's actions most often reflected what was expected (Fig. 3).

The children in the three-year-old group observed their classmates in all the activities, except those with less attendance. This type of interaction stood out in A7 ($n=10/13$, 76.9%) and A4 ($n=7/10$, 70%). This might be due to the children's little previous experience with tasks involving identifying and comparing. This was also observed in the five-year-old group, though less often. Unlike in the five-year-old group, this type of interaction was observed with a high frequency in the rest of the activities, except in A1.

The children interacted with adults twice in A8 and once in A1 and A6, in which they shared their findings related to the movement of the seeds, the books that they were reading and the associations that they made. However, the number of interactions increased in A7, when the teacher had to warn them five times about the danger of placing the nuts in their mouth. Although actions had been taken to prevent the children from opening the containers that held the shelled nuts, they were still able to open them.

Discussion

The free-choice learning environment on plan diversity that was evaluated sheds light on the importance of interacting with materials and people to stimulate science learning, as indicated by authors such as Nayfeld et al. (2011) and Shaby et al. (2019).

Thinking about designing these spaces with objectives that yield opportunities for intentional science learning (Fleer et al., 2014) is no easy task, because it involves creating activities with materials that encourage children to complete scientific actions of different levels of complexity that consider diversity of the classroom.

The study's results show clear differences between the actions that can be taken by the five-year-old group and the three-year-old group. The three-year-old group's achievement of the FSLE activities' intended objectives was seemingly related to: (1) their knowledge of the materials presented and/or (2) their potential to be 'handled'. The first case was observed in A1: the children were used to looking at images in books, since there was a library in the class. However, because they were not familiar with the nuts, they had trouble identifying nuts their shell in A7. The second case could be seen in A4, an activity with sensorial requirements in which the children were encouraged to touch some objects without looking and notably were 'pricked' by them, and in A8, where they were encouraged to experiment with and check phenomena with which they were relatively familiar because they happened every day. In this activity, the children could generate wind blowing against themselves, other classmates or even a surface and experimented with how some 'things' moved in the wind and other 'things' did not, confirming the effects of currents of air.

The five-year-old children managed to achieve more of the objectives planned in the activities. This could be due to: (1) greater familiarity with some scientific procedures such as observing, comparing and classifying and (2) greater knowledge of the materials included in the activities and knowledge related to the key ideas of the space. For example, the children could use a magnifying glass to make careful observations about leaves (A2) and describe features of the materials by identifying the pine cones with the photographs (A4).

The results corroborate those obtained by Nayfeld et al. (2011) in other contexts in which children work independently. Thus, those who design an FSLE must consider the children's level of knowledge about the materials included in the activities and about the scientific skills on which they are supposed to work. This interaction between skill and knowledge matches Larimore's (2020) definition of scientific practice in early childhood education.

The implementation of scientific practices in the early stages of education requires the introduction of progressive scaffolds that help the children to increase the complexity of their scientific models (Monteira et al., 2022). To be able to compare, associate or generalize ideas related to certain facts or natural phenomena, it is necessary to initially develop observation skills and a language that allows externalizing these observations. Therefore, the fact that the intended objectives with higher-level cognitive demands in a given activity in the FSLE were not achieved by the younger children should not be seen as a problem, but rather as a learning opportunity.

Another thing to point out regarding the materials used in the FSLE's different activities and their arrangement is the importance of consistency between the objectives that are expected to be achieved and the materials included. While some activities encourage children to go beyond what is expected from a scientific point of view (in A4, for example), others encourage actions unrelated to what was intended. The latter point was clearly visible in A6, where it was not a good design decision to include colored paints.

However, evaluating these learning environments is not only limited to whether or not the children are familiar with the materials or the requirements of the FSLE activities. The types of social interactions that take place are also factors to consider (Mateo & Sáez-Bondía, 2022; Nayfeld et al., 2011).

Three main types of interactions were observed during free-choice periods in this study: observing classmates, sharing with them, and sharing with an adult. Interactions focused on watching peers were more common when the children knew little about how the activity worked. This was noticeable in nearly all the activities with the three-year-old group, whereas it only appeared with the five-year-old group in activities requiring more complex cognitive actions, such as comparing and identifying. These observations promote vicarious learning (Bandura, 1977). How a classmate looks or thinks can help others to understand phenomena from other perspectives and might prompt them to justify their own thinking. Children shared findings and/or materials with their classmates in activities that presented challenges that they understood. Therefore, these interactions were more frequent in the five-year-old group and gave rise to intended or unintended actions that nevertheless promoted science learning. Finally, interactions between children and the adult also varied by age group. The three-year-old children's actions were mostly related to behavior, while the five-year-old children tended more to share discoveries that impress their classmates.

To build scientific concepts in early childhood education, children must be in contact with others during learning situations (Siry & Kremer, 2011). Small group relationships are encouraged in this environment, which are more suitable for developing science learning by experimenting with materials (Malaguzzi, 2001). Even so, more guidance from the teacher is required to develop more sophisticated models (Haldon et al., 2022; Mateo & Sáez-Bondía, 2022; Nayfeld et al., 2011).

Therefore, teachers must consider the materials, the interactions and the children's prior knowledge when designing, implementing and evaluating an FSLE. The inclusion of scientific materials and the fact that the children know how to use them are not enough to ensure that they learn. Consideration must therefore be given to the interactions that take place in the classroom. Incorporating these environments in the initial stages of a teaching and learning sequence (TLS) can be a focus of interest for working on it more directly. Thus, this study opens the door to following up on including single-subject FSLEs at different periods of a TLS.

Educational implications

The purpose of DBR is to produce contextualized theoretical design principles (Anderson & Shattuck, 2012). Considering this study's results, we can suggest some guidelines for designing an FSLE that can be used at different levels of education.

The FSLEs provide a possibility of autonomy in both choice and action that makes it easier to plan activities with different objectives. In other words, when designing each activity, it is advisable to define a set of objectives with different cognitive demands. In this way, the activities taking place in a certain space can be used for different levels of education, where younger children can get familiar with scientific content and older ones can explore it in further detail. A properly planned FSLE can be used at different grade levels, in groups of the same grade, or even in interlevel contexts, given the individual differences typical of early childhood education and despite the effort required to design and craft the activities for the space.

It could also be interesting to use FSLE at levels that transition into elementary school, because this can: (1) soften the landing in stages by continuing with similar classroom dynamics (González-Moreira et al., 2021); (2) assess the children's starting levels; and (3) pay attention to the diversity of these stages, encouraging autonomy.

The antecedents of FSLEs in the bibliography focus on informal contexts that included activities addressing a wide range of subjects (animals, forces, minerals and others). However, we believe that single-subject FSLEs could bring several benefits. First, they expand scientific models by working on skills and knowledge about a single subject, which can be difficult to cover when many topics are presented together. Second, they promote the consistent sequencing of TLSs for teachers and students alike and can be integrated at different times according to what the context requires: they are useful as a starting point for establishing common grounds of interest among the students; they can be helpful at the end of the TLS to recap and evaluate; and they are available in intermediate periods to consult and explore new interests. Finally, they introduce interdisciplinary projects in schools, without losing the guiding thread between areas of knowledge.

Regardless of the educational recommendations resulting from evaluating the learning environment covered in this study, any teacher inspired to use the design presented here should bear in mind the reason for using it and the characteristics of the context in which it will be implemented.

Conclusions

The field of research on learning environments continues to expand. In a recent review paper published by Fraser (2023), he notes a renewed interest in learning environments' physical spaces. However, he warns that it is important that these studies do not only focus on the psychosocial impact of spatial modification. As Kokko and Hirsto (2021) propose, for physical space to be transformed into a learning environment, social and material interactions need to be considered. The present work, in the context of science learning in early educational stages, shows the evaluation of a learning environment in which the spatial layout is modified. Nevertheless, unlike those studies criticized by Fraser, the one presented in this paper also analyses the implications for learning and the development of scientific skills that derive from such a change on how the space is used and from the introduction of different materials. Moreover, the literature shows that it is a challenge for early childhood teachers to design science-related activities (Leung, 2023). The principles for the design of intentional learning environments drawn from the present research can both help teachers to design and new approaches to science learning in early childhood and contribute to the body of knowledge that has been generated around learning environments in which the physical space of the classroom is modified.

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