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Recognising patterns of authentic inquiry-based approach to foster children's scientific reasoning process

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The objectives of the ONU Agenda 2030 and the actions outlined in 2020 in the European agenda for skills underline the importance of bringing students closer to STEM (Science, Technology, Engineering and Mathematics) subjects and consequently promote scientific education to accompany schools in the ecological and cultural transition. The global and European recognition of the importance of developing learning paths that immediately introduce children to scientific disciplines raises the need to think about learning environments and teaching paths that effectively promote the development of scientific thinking. The approach to STEM disciplines should be interdisciplinary and develop disciplinary and transversal skills, such as creativity, critical thinking, reasoning, and social, economic and environmental skills. The Investigative Science Learning Environment (ISLE) is an example of an authentic inquiry approach, which promotes and fosters students' scientific abilities with active learning settings and activities. In this study, we focus on an example of how to develop children's scientific thinking using the ISLE approach. From a cognitive and non-cognitive point of view, we recognise the main features of the activated process in the learning sequences and identify patterns in their physical "babbling" reasoning, which is sustained by the teacher's scaffolding.

KEYWORDS

scientific reasoning, authentic inquiry, scaffolding, STEM education, physics curriculum, ISLE approach

1 Introduction

Projects that promote STEM in learning paths should be based on solid theoretical and methodological foundations, which imply identifying principles that can guide the design of learning environments and the structuring of activities, both from a pedagogical and educational standpoint.

According to a socio-constructivist perspective, we can understand how students develop scientific thinking by observing their relationship with the social, cultural and environmental situations they experience (Fleer, 2021; Fragkiadaki et al., 2021).

The social and environmental context plays a significant role in shaping learning processes. The types of participation available to children in learning environments can vary, leading to different experiences. It is, therefore, fundamental to understand the role of the environment in influencing the learning path and understand how contextual factors can take on meanings during children's growth (Stephenson et al., 2022; L. Vygotsky, 1994).

Acting on learning contexts means introducing variations in the different forms of participation that children can undergo experiences that shape the manner in which they explore STEM disciplines. Therefore, different forms of participation can influence how events

are perceived and the relationship that the individual creates in social reality (Vygotsky, 1998).

Furthermore, according to the social constructivist perspective, learning is understood as a process of collective knowledge construction, where the interaction between peers, sharing, and comparison are considered central aspects. Thus, learning takes place in collaborative activities, where space is given for social interaction between participants within motivating activities that stimulate active participation and interest. Students' active participation and involvement are crucial to promoting learning and stimulating children to think scientifically.

Accordingly, school contexts should promote learning activities that allow students' participation, where they can experience relevant and engaging activities, initiate problem-solving processes and develop critical thinking. In this way, children have the opportunity to build and share content knowledge by themselves, testing their own ideas and hypotheses, comparing the new experience with the previous ones, and finally integrating the concepts acquired with pre-existing ones (Zull, 2002). The meaning of knowledge is therefore formed in a shared and negotiated way, through comparison and exchange of ideas (Scardamalia and Bereiter, 1996).

The teacher should, therefore, support children in building this learning community where they can learn intentionally and actively pursue a goal. It means supporting learning by proposing authentic tasks: encouraging opportunities for shared reflection, activating scaffolding processes and knowing how to grasp and enhance the intuitive strategies that students can activate to solve a problem or understand a phenomenon (Brown and Palincsar, 1989; Cobb et al., 1992; Collins et al., 1987).

The following theoretical introduction briefly describes the main reference frameworks guiding this research and contextualises its aims and goals. Firstly, the features of the scaffolding process are introduced. Then, scientific thinking about children's development is presented to recall the theoretical starting point for our study. Lastly, a highlight into learning by inquiry is furnished. This enables us to move toward an educational perspective based on the experiential learning cycle and activation of cognitive and non-cognitive processes of authentic scientific investigation.

2 Pedagogical framework: learning by inquiry

The concept of an inquiry-based teaching and learning approach encompasses a range of educational ideas, as highlighted by Dobber et al. (2017) and Pedaste et al. (2015). Within this broad framework, we can identify three main approaches that share similarities in terms of their purpose and application: problem-based learning, project-based learning, and inquiry-based science learning. Among these kinds, we identified that inquiry-based science learning could satisfy the requirements for an Early Physics design, calling and considering Early Physics (Bologna, 2023) as a domain of teaching Physics even in primary education.

Within the domain of inquiry-based learning, there is no consensus about the meaning of the term "Inquiry" (Dobber et al., 2017; Worth and Grollman, 2013); one of the acknowledged definitions is that scientific inquiry learning is a tool for developing scientific thinking strategies and deep understanding of science content

(Ben-David and Zohar, 2009). Therefore, "Inquiry" pertains to the processes scientists employ when investigating the natural world, wherein they put forth explanations incorporating evidence collected from their observations. The term also includes the activities of students—such as posing questions, planning investigations, reviewing what is already known, and considering experimental evidence that mirrors what scientists do (Martin-Hansen, 2002).

In a certain sense, the nature of science embodies strategies for structuring content knowledge for its teaching (Dobber et al., 2017). The learning process follows a cyclical pattern, reflecting the rhythm and development of children's reasoning processes (Kolb, 1984; Zull, 2002). Adheres to a four-stage cycle, wherein four adaptable and interconnected learning modes are engaged. Effective learning is observed when children advance through this cycle of stages:

1. Having a concrete experience;
2. Observation of and reflection on that experience;
3. The formation of abstract concepts (analysis) and generalisations (conclusions);
4. Used to test a hypothesis in future situations, resulting in new experiences.

In defining learning by inquiry, it is noteworthy to underline the cognitive processes involved in these practices (Kuhn et al., 2000; Zimmerman, 2000; Zull, 2004).

Secondly, it could be useful to compare the cognitive and non-cognitive processes involved in authentic inquiry (the inquiry performed by scientists in their scientific practices) and the inquiry performed in science classrooms (Chinn and Malhotra, 2002). These facets contribute to learning effectiveness by inquiry into achieving learning outcomes.

2.1 Cognitive processes in inquiry practices

One of the primary goals of inquiry-based approaches is to support students in scientific reasoning (Kuhn et al., 2000). However, there are significant differences between the cognitive processes activated in school tasks and those required in scientific research conducted by scientists (Chinn and Malhotra, 2002; Sin, 2014).

According to the taxonomy proposed by Chinn and Malhotra (2002), the inquiry practices adopted in educational settings activate different cognitive processes compared to those involved in authentic scientific inquiry. In the context of authentic research, scientists independently formulate research questions, develop complex procedures to address them, and employ advanced techniques to control potential biases in their observations. In contrast, in simplified school-based inquiry, students typically respond to questions posed by the teacher, follow pre-established procedures, and conduct observations without systematically controlling for biases.

The way results are analyzed and explained also differs significantly. In authentic scientific inquiry, scientists repeat measurements and procedures multiple times before drawing conclusions, whereas in school-based inquiry, students often rely on a single measurement or procedure to formulate their findings. Moreover, the reasoning employed varies between the two contexts: scientists combine multiple forms of reasoning, such as deductive, inductive, or comparative reasoning, while students tend to use simpler reasoning strategies.

Finally, the process of generalizing results follows different paths. In scientific research, scientists compare procedures and measurements to identify broader patterns and formulate general theories. In contrast, in school-based inquiry, students typically replicate the same situation without actively exploring generalization. When choosing an inquiry model, we answered two cognitive demands: enacting a complete learning cycle and developing scientific reasoning skills based on the cognitive processes of authentic inquiry. To meet these two requirements, we chose the inquiry-based approach called Investigative Science Learning Environment (ISLE) (Etkina et al., 2019). This reference framework satisfies and promotes the cognitive processes underlined in the experiential learning cycle denoted (Brookes et al., 2020). Encountering all the requirements, we recommend its adoption even in an Early Physics teaching domain (Bologna, 2023). The Investigative Science Learning Environment (ISLE) allows students to engage actively in scientific practices. In this setting, learners think and act like scientists by making observations, developing hypotheses, testing their predictions, and refining their ideas based on evidence (Etkina et al., 2019; Brookes et al., 2020). It is an intentional-holistic learning environment: intentional to curriculum design, which means how and what students learn has the same importance, whereas holistic regarding learning Physics as a whole, coherent frame. The two main goals of the ISLE approach are:

- “Engaging students in the process of doing physics with a simplified model of the actual logical progression of the activities of physicists” (Brookes et al., 2020);
- Improving students’ well-being while they are learning Physics, motivating them to be engaged in the process of doing Physics (Etkina et al., 2019).

Collaborative learning is central to this approach, with students working in groups, discussing, and interacting to deepen understanding and build new knowledge. ISLE also promotes using various representations—graphs, equations, diagrams—to foster comprehensive concept understanding. The ISLE approach embraces how cognitive and non-cognitive processes interconnect (Brookes et al., 2020). It highlights the role of representations and physics practice from the cognitive side, and socio-cultural and human aspects from the non-cognitive side, discussed next.

2.2 Non-cognitive processes in inquiry practices

The research highlights how cognitive functions and sensorimotor processing are closely interconnected processes (Dehaene, 2019; Zull, 2004). According to the theoretical perspective of embodied cognition, interactions of the body with the external world contribute to shaping our thought processes, emphasising the central role of bodily experience in cognitive development. Learning processes can be supported by motor experience if learning environments are designed to enhance experimentation through body movement. Therefore, it is a matter of considering cognitive-body components as a resource and an opportunity to enhance the various ways learning occurs and incorporate them into the teaching experience (Glenberg et al., 2013; Gregorcic et al., 2017; Weidler and Abrams, 2014; Wilson, 2002).

Based on the theoretical framework of embodied cognition, action and perception are inseparably linked, where sensory-motor experiences of the external environment are based on cognitive processes (Glenberg et al., 2013). The thought process can be built from children’s concrete experiences in learning contexts, as cognitive aspects and sensorimotor processing are closely linked (Wilson, 2002). Research has demonstrated a connection between activating learning-related brain regions and tasks, including imitation, modelling other people’s movements, and observation (Rizzolatti and Craighero, 2004). For example, some studies show how attention and memory improve when using hands is associated with the learning process (Weidler and Abrams, 2014). Other studies support evidence emphasising the positive effects of movement and gesture use in mathematics learning (Riley et al., 2016). Cognitive processes are closely linked to emotional, motivational, and physical involvement during activities. Therefore, it is evident how cognitive functions, sensorimotor processing, and social and emotional aspects are closely interconnected.

2.3 Teacher strategies: the role of scaffolding

For Bruner (1976), learning develops in environments that support inter-subjectivity. Children are not “containers” of information; rather, they are active and intentional (acting in relation to an internal purpose) from the early stages of childhood; they are capable of meaningful interactions with the cultural models present in society. Therefore, from a pedagogical point of view, it is important to incorporate all these elements into the design of educational initiatives and focus on the intentional activities carried out by children.

Scientific thinking can be promoted by offering children the opportunity to experience stimulating learning environments that allow for exploration and investigation; at the same time, it is important to consider how moments of exchange and intentional sharing occur during this process and build inter-subjective relationships. During the moments of sharing, processes that support learning, called “scaffolding” are activated. This metaphor indicates the contribution given by adults or by most expert children to the other in order to stimulate the development of a higher level of competencies. During the scaffolding process, teachers can use specific linguistic acts that can orient the children’s attention and indicate to them how to act and reflect on their experiences. The concept of scaffolding, therefore, indicates the arrangement of the interpersonal relationship between adults and children and between peers, mediated by the arrangement of objects and the environment, to promote development and learning (Belland, 2017; Bruner, 1976, 1990; Hsu et al., 2015; Lee and Tee, 2021; Rogoff, 1990).

The scaffolding metaphor focuses on the inter-subjective dimension (Palincsar, 1986): it underlines how scaffolding is not a unidirectional process from the most expert to the beginner but consists of the exchange and shared reflection between the ones involved in carrying out an educational activity. As a result, not only the adult supports the child, but peers also support each other when engaged in an activity that stimulates them. Furthermore, the activity in which children are engaged can evolve, changing objectives, strategies and tools. Finally, the support is not only the intervention of

the adult but also, more indirectly, the organisation of spaces and objects, which can allow wider possibilities for developing the inquiry experience. From a scientific thinking development perspective, the notion of scaffolding extends toward designing activities and tools that can effectively sustain student learning processes.

Scaffolding strategies, therefore, affect not only interpersonal relationships but also the learning environment itself: the tools and resources are used to become the scaffolding that supports learning (Bell and Davis, 2000; Puntambekar and Kolodner, 2005; Puntambekar et al., 1997; Tabak and Reiser, 1997). Structuring the activity and the environment becomes part of the scaffolding process, which supports the learning experience and the process of building shared knowledge (Kolodner et al., 2003; Sandoval and Reiser, 2004). The activities' design and the tools chosen help children focus attention on relevant aspects of the task, make implicit processes visible, and encourage interactions and comparison.

In this study, scaffolding is not only a supportive strategy but represents a fundamental condition for activating children's reasoning processes. The teacher's scaffolding enables the transition from concrete experience to abstract conceptualization, which is essential for the development of scientific thinking.

3 Learning environment

3.1 Setting

This paper presents a case study conducted in a 5th-grade primary school classroom, with the participation of ten students (aged 10; five girls and five boys). The activity took place within a broader interdisciplinary project carried out in collaboration with a dozen of schools in the Friuli Venezia Giulia Region (Northern-East Italy) and the Departments of Physics and Humanities at the University of Trieste (Italy). The case-study methodology (Creswell and Clark, 2003, 2017) lets us focus on the process in which children are involved in a specific time and for a well-designed activity (Tannenbaum and Spradley, 1980).

The general project strives to develop students' skills in scientific topics to support the development of scientific thinking, including analogical, abductive, inductive, hypothetico-deductive reasoning, and the capability to use critical thinking in understanding reality. The interdisciplinary approach integrates disciplinary languages of physics with the socio-constructivist pedagogical perspective.

The project's phases included an initial training course for teachers on the inquiry-based learning approach and laboratory teaching, with examples consistent with the Italian National Guidelines (MIUR, 2012) regarding the thematic cores of physics.

We developed the training program for in-service teachers according to the DHAC framework Developing Habits through Apprenticeship in Community (Etkina et al., 2017). Behind the scope of this paper, what is notable to describe is that as a part of this program teachers acquire new habits of practices, coached by researchers in their classrooms' activities. This is developed into a co-design phase of learning environments and methodologies that can encourage the development of scientific thinking for STEM learning based on inquiry-based learning. Then, there is practical instruction, where teachers observe the researchers doing the activity planned together. The case study we examined exemplifies this coached

apprenticeship for in-service teachers, featuring mainly the scaffolding process.

Teachers involved in the program could then freely choose to participate in the research with their classes, as recruited for the case study. We adopted a recruitment policy guaranteeing anonymity, informed consent and the protection of sensitive and personal data in accordance with Legislative Decree nr. 196 of 30 June 2003, "Code regarding the protection of personal data" and the research ethics code established by the University of Trieste.

The content topic of the activity proposed concerned the uni-dimensional description of motion in Physics and took place in 2 meetings (2 h per meeting). The design was planned with the teacher, according to the ISLE approach (Etkina et al., 2019) and the materials build by ISLE-developers. It was characterised by the following aspects, which theoretically ground the approach itself (Brookes et al., 2020) and define the learning environment with the following setting features:

- Structuring student-centred activity (Vale et al., 2010);
- Organising working and collaborative groups for active learning (Rogoff and Toma, 1997);
- Encouraging conceptual management of representations plurality for building knowledge (Potvin, 2022).

The activity took place in an open classroom designed to foster embodied engagement, featuring central seating arranged for groups and ample space for various tasks. Each group actively participated by observing and describing the process of rolling a ball, incorporating embodied actions such as using a sand sack to stabilize the ball while listening to a metronome, or clapping and stomping to maintain rhythm. These embodied actions—launching and following the ball, positioning the sand sacks, clapping hands—were integral to their experience, emphasizing physical participation. The activity adapted to different parameters, such as changing the ball, launching it on a carpet, or pushing it with a broom, yet the emphasis remained on the embodied involvement of each participant throughout the process. Then they recorded their observations in whiteboard notes, discussing and trying to draw picture of the motion pattern recognised.

3.2 Learning objectives

The learning objectives were both cognitive and non-cognitive:

- Design learning environments featured to achieve well-defined outcomes and skills development;
- Propose project activities that encourage the sharing of scientific models that stimulate initiative, active participation and reflection (through the inquiry-based learning approach);
- Promote interaction methods that stimulate the social dimension and the building of skills through collaboration between peers;
- Encourage support strategies from teachers that facilitate learning experiences through scaffolding processes.

The activities were focused on basic physics principle—one-dimensional motion—because it involves prediction, hypothesis testing, and cause-effect reasoning, which are key for developing children's scientific skills. Here, effective learning is defined not only by

the acquisition of factual knowledge, but also by the development of higher-order thinking skills such as reasoning, and the ability to transfer learned concepts to novel situations. This multidimensional understanding of effective learning provides a robust framework for assessing the impact of the activity on children's cognitive development.

3.3 Pedagogical format

The pedagogical format was inquiry-based and aligned with socio-constructivist principles. Students engaged in guided experiments, such as observing the rolling of a ball under different conditions (e.g., on a carpet, pushed with a broom, or stabilized with sand sacks). These concrete explorations were complemented by group discussions and collective representation of the observed patterns on a whiteboard.

The teacher and researcher provided scaffolding throughout the process, supporting students' attempts to link their concrete experiences with abstract reasoning. In this way, the activity created a dynamic environment where conceptual understanding emerged through embodied engagement, social interaction, and structured guidance.

Analysing the learning sequences' features, we wanted to highlight how the inquiry-chosen approach promoted the development of scientific thinking in a socio-constructivist learning environment. Our work, thus, would answer the following research question:

Which are the recognisable patterns in the learning sequence that feature an authentic inquiry-based investigation, ensemble scaffolding, and socio-constructivist processes for scientific thinking development from a cognitive and non-cognitive standpoint?

Thus, this work aims to analyse how the structure of interaction and participation between teachers and children in an ISLE process can support the development of scientific reasoning. Specifically, the goal is to identify and recognise recurring observational patterns in children's discourses, embodied engagement and contextual social interactions. All of them shape and build their thought processes. Accordingly, we identified specific categories of analysis directly linked to their different levels of reasoning. Furthermore, we used these categories to pinpoint how scaffolding processes can stimulate the construction of scientific thinking.

4 Results to date/assessment

4.1 Processes and tools

The case study generated a rich set of observational and interactional data documenting how students engaged in the inquiry-based learning sequence. We acquired 22 recorded sessions that span the two activity days, encompassing working group time. A cumulative 240 min of video data were gathered using two cameras. One hand-held camera tracked children's movements, while the second, mounted on a tripod, captured the main learning area. All the data collected were digitally stored and tagged in conjunction with the digital video observations. In particular, we framed the video-recorded data into meaningful and explicative vignettes (Gregorcic and Haglund, 2021; Gregorcic et al., 2017), using them in the data analysis. These video recordings were complemented by whiteboard notes, drawings produced by students, and researcher field notes.

We have transcribed the video recordings into children's spoken language (Italian). We have used HappyScribe software¹ to transcribe student utterances and refined all the transcriptions by listening more to the classroom discourses. We started our analysis by dividing the entire discourse transcribed into frames. One speaker (children or teacher/researcher) defines each frame. We assigned a general key name for each child to maintain their anonymous profile in the transcription files.

Each frame was analyzed according to specific categories that align with our research objectives and questions, based on the theoretical frameworks adopted and the ISLE activity conducted. The categorization allowed us to examine both cognitive and non-cognitive aspects involved in the children's learning process and the teacher's scaffolding strategies:

- Teacher/Researcher's discourse: Examined for scaffolding strategies and support offered to students.
- Children's discourse: Investigated in terms of cognitive processes, including thinking and reasoning, as well as non-cognitive aspects, such as emotional and behavioral components.

The most informative data could be collected by analysing the link between categories, how they are nested in the process and how many times they are recognisable in the experiential learning cycle.

Furthermore, we used the identified categories interrogating the transcriptions and searching for how these categories were linked and nested one to each other. We organised the results into network graphs to highlight the nesting paths. We used Flourish application² as visualisation tool for our scope. Each node of the graph represents one category: larger nodes mean higher frequency in the transcription analysed.

Moreover, we selected some recorded sessions and analysed them by looking at the discourse duration timing. We added this analysis in order to give completeness to our case-study research, using quantitative data to support the results achieved. Time duration-frame analysis could inform us about children: cognitive processes (spoken time reflects the ongoing process of thinking externalised by talking), non-cognitive processes (spoken time duration reports children's engagement and active participation). This analysis also informs us about the teacher/researcher scaffolding process: the spoken time reflects how supportive is the external intervention in the learning sequence.

4.2 Data already gathered

We recognise some features in the learning process that lead us to shape how to develop an authentic inquiry-based investigation and how this one influences children's cognitive and non-cognitive processes, referred to as scientific thinking development. Preliminary coding highlights recurring patterns in which students moved from concrete experience (handling the ball, synchronizing rhythm through clapping/stomping) to abstract conceptualization (drawing motion paths, verbalizing causal relations). Teacher scaffolding was found to play a pivotal role in maintaining this transition, offering prompts that encouraged students to externalize reasoning and compare different representations.

¹ Available online at: <https://www.happyscribe.com>.

² Available online at: <https://app.flourish.studio>.

In the following, we examine the results of the data analysis. Firstly, we will detail the features of the video-transcriptions analysis. Here, we report the meaningful frames (among all analysed) for each category.

4.2.1 Patterns identifying the scaffolding processes

From simpler to sophisticated teacher/researcher intervention scaffolding levels, these are the categories identified:

- S1-Helping children with operative/procedural instructions: setting activities; giving materials/tools; listing procedures to execute; resolving incoming technical/practical issues; promoting stepwise tasks.
- S2-Facilitating children's discourses and discussions: promoting shared dialogue, without giving immediate feedback to children interventions but activating peer-talking and discussing. Reformulating briefing children discourse for enhancing and externalising their thinking embraced in their speeches.
- S3- Helping children in representational stuff: offering during the activities multiple representations (sketches, words, schemes, diagrams, symbols) to develop and support the thinking process and to activate the reasoning process.
- S4-Guiding children in reasoning process: creating educational opportunity where children empower the reasoning process activated in order to resolve new unknown situations where they work by analogic and hypothetico-deductive reasoning.

4.2.2 Patterns identifying the cognitive processes

Investigating the video transcriptions, we underpinned these categories, featuring cognitive processes involved during the learning sequence:

- C1- Collecting information from experience: repeating many times the same tasks, for acquiring confidence in the investigation required.
- C2- Representing information in multiple modes: describing observation from experience done using words; drawings simple illustration of their description; elaborating schematic patterns to frame out their ideas.
- C3- Reasoning activation for abstract conceptualization: using different representations for explaining their observations and descriptions; employing different forms of reasoning (mainly analogic) for giving meaning to their ideas.
- C4- Reasoning for active experimentation based on acquired ideas: employing different forms of reasoning (mainly hypothetico-deductive); using acquired ideas as starting point for concepts generalisation (as inductive reasoning process).

4.2.3 Patterns identifying the non-cognitive processes

The largest group of identified categories belongs to the non-cognitive process. We found five categories embodied by children during their scientific activity:

- NC1- Spontaneous embodied involvement in the learning tasks: gesturing with hands/arms for time measurements; freely moving

in the space of the learning environment; taking part in working group activities with no necessary selected roles.

- NC2- Activated embodied involvement by the requested collaborative learning tasks: participating in concrete learning experiences, involving all the body in the tasks requested, paying attention to their peers and supporting them if needed.
- NC3- Emotional externalisation through non-verbal expression: laughing accomplished by the positive feedback in what doing; expressing satisfaction with outcomes achieved.
- NC4- Emotional externalisation through verbal expression: significant involvement sustained by words of enthusiasm; freely expressing positive and negative feelings.
- NC5- Attitude toward tasks' execution (as a behavioral component): showing active and coherent participation activated by learning tasks.

Then, for a more detailed analysis, we searched for the number of times the categories were recognisable in the learning sequence. [Figure 1](#) plots a descriptive and informative analysis result and shows the distribution among categories of each process aspect.

Furthermore, we could relate these categories to the experiential learning components based on cognitive and non-cognitive categories recognised in the video- transcription analysis. We cluster them linking categories ([Table 1](#)).

To help define experiential learning components, we plotted the data collected in the stacked bar ([Figure 2](#)) to show how each cognitive and non-cognitive category contributed to shaping the learning cycle.

Then, we plotted the different categories recognised as a network graph to provide a more detailed insight into our data analysis ([Figure 3](#)). Here, we present a plot for a recognisable complete learning cycle in the learning sequence analysed. It is an extract of all the frames analysed and informs how the categories are linked to each other and to what extent they contribute to the teaching/learning process.

Each category is plotted in the graph with different colours belonging to different processes (cognitive, non-cognitive from the children's point of view, and scaffolding from teacher/researcher standpoint). Higher bubbles mean higher frequency. The arrows underlie the relation between the categories: one arrow is a one-directional relationship, and two arrows are bidirectional. We plotted data in network graphs to visualise the linked relationship between categories better.

We can recognise two interesting trends well: the first one is the nested categories, and the second one is the growing effect in all the processes. From children's points of view, these trends suggest they are fully engaged in the learning environment: cognitive and non-cognitive components work together without constraints. We observe that non-cognitive category activation anticipates the cognitive one. Intertwining cognitive and non-cognitive processes, children shape their experiential learning process. This key aspect strictly depends on the learning sequence adopted in the ISLE framework. From a teacher/researcher standpoint, the facilitator's role is prevalent during the activity, balanced by the role of improving cognitive performance and process (in terms of reflection and abstraction of experiential learning activation). This also emerges from analysing the discourses of the transcribed audio. As it is plotted in [Figure 4](#), kids' discourse has a prevalent role in all activity covering at least the 50% of the time. The teacher and researchers' time duration is consistent with the scaffolding role evidenced in the categories analysis.

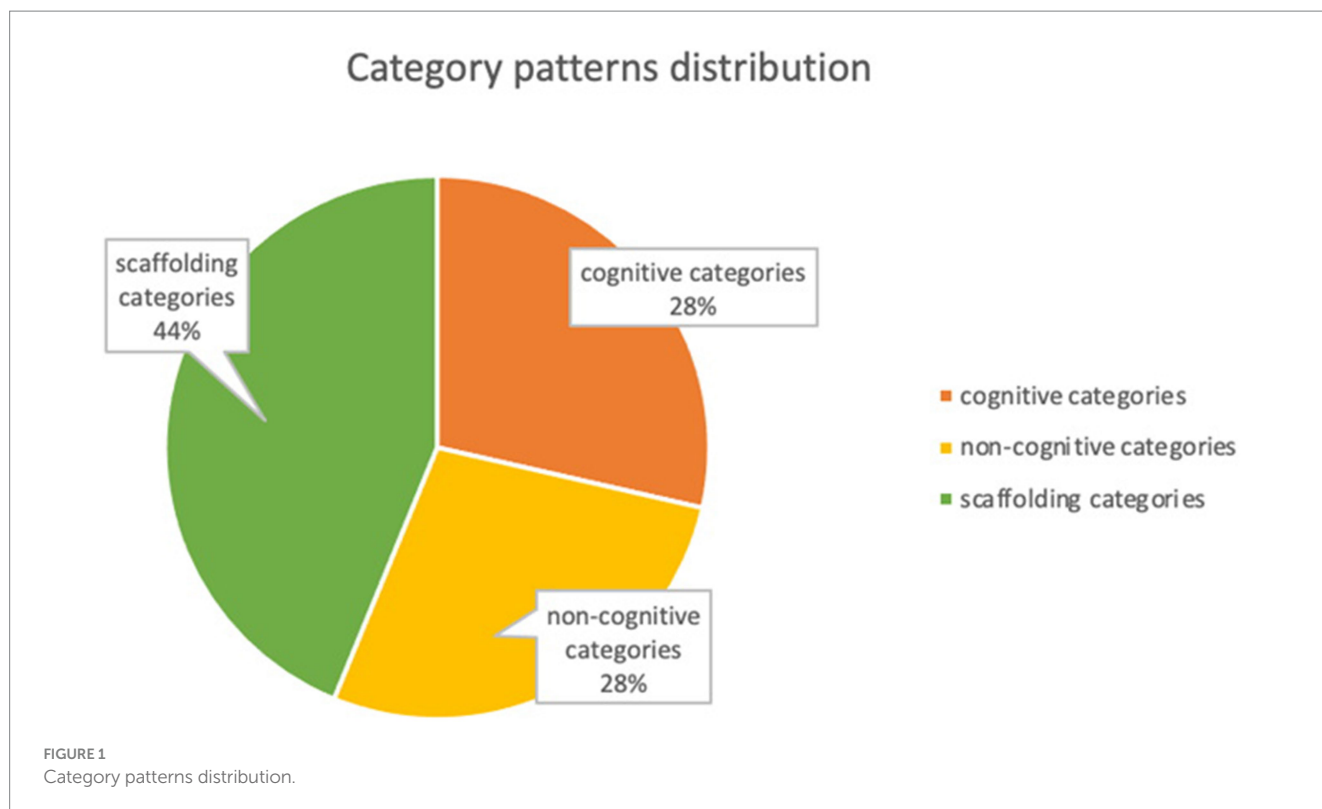


TABLE 1 Features of the experiential learning process designed by cognitive and non-cognitive categories identified.

Component	Feature identified	Linked category patterns
EL1	Concrete experience	C1, NC1, NC2
EL2	Reflective observation	C2, NC3
EL3	Abstract conceptualisation	C3, NC2, NC4
EL4	Active experimentation	C4, NC2, NC3, NC4

5 Discussion on the practical implications, objectives and lessons learned

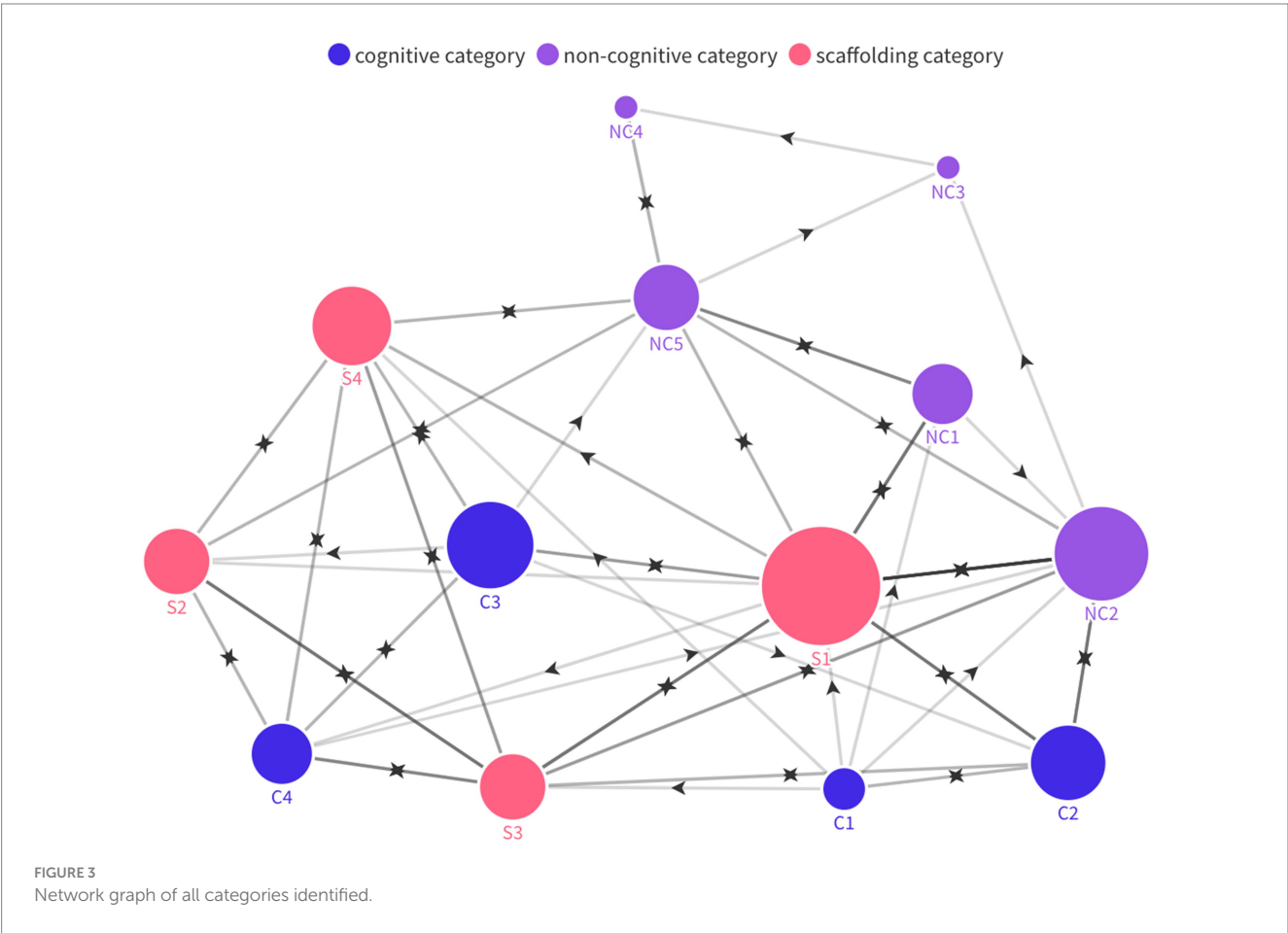
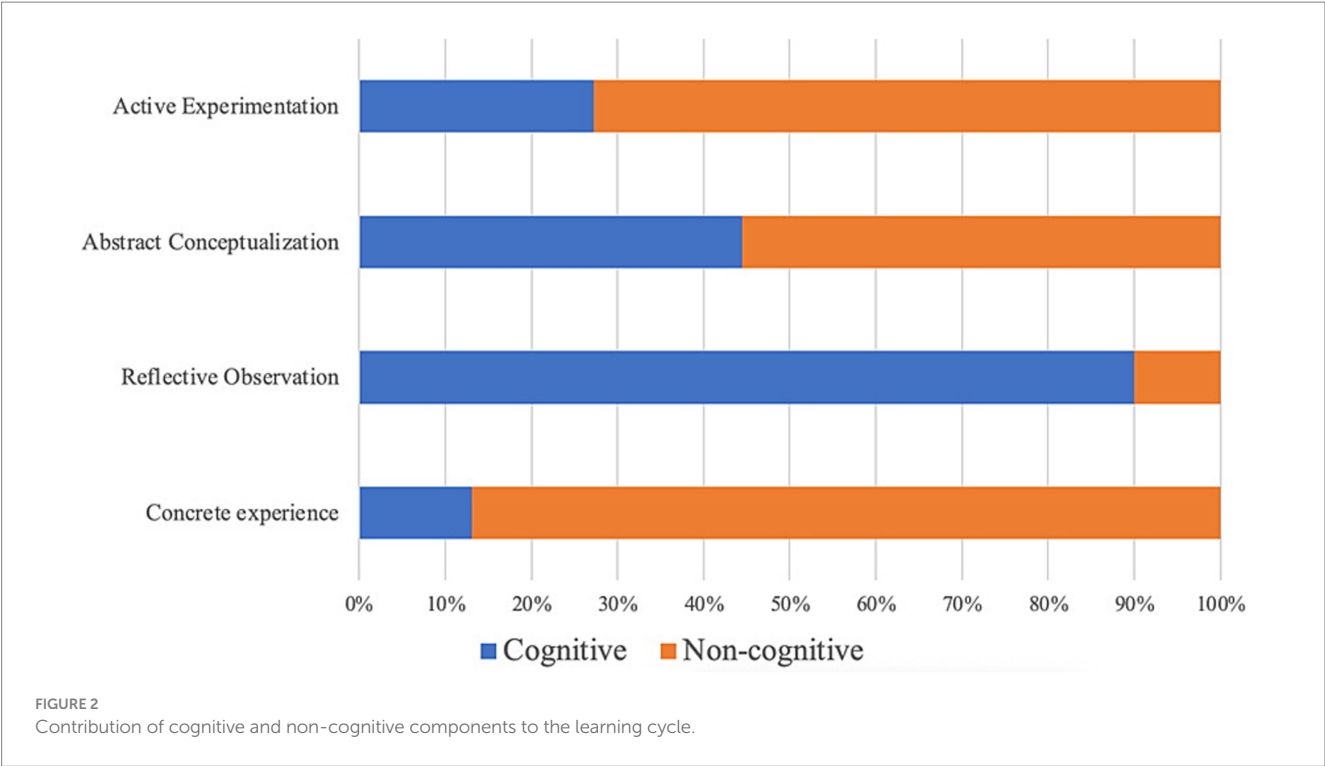
This case study demonstrates that carefully designed inquiry-based environments, when supported through flexible scaffolding, enable primary school students to engage in authentic scientific reasoning. One of the central objectives—promoting the transition from concrete experience to abstract conceptualization—was clearly observable in the ways children moved from embodied engagement (rolling the ball, clapping, placing sand sacks) to the construction of abstract motion patterns and their generalization to new contexts.

We have identified different characteristics of the scaffolding process during the learning activities. The fundamental characteristic is that the teacher never provides the children with pre-elaborated knowledge but continuously encourages them to construct knowledge themselves. Throughout the activity, there is never a factual statement of conceptual knowledge.

This characteristic is inherent in the type of learning sequence that has been implemented. Even in the concluding moments of the activity, children were guided to autonomously re-elaborate their experiences. This type of scaffolding is indicative of an inquiry-based educational process. From the conducted analysis, it is evident that the characteristic of an authentic inquiry process unavoidably demands tasks from the teacher, as identified in the scaffolding (Belland, 2017; Palincsar, 1986).

The features of the identified cognitive processes have highlighted the importance of representations in structuring children's scientific thinking. Representations (from verbal to pictorial) demonstrate sophistication in children's thinking, allowing recognition of specific scientific reasoning. This process is consistently used by children in various moments of the activity, showing an increasing level of abstraction (indicating a mental representation of the constructed physical concept) and complexity. As it can be seen in the pictures below (Figure 5), which highlight different levels or orders of abstraction (even more specialized). They draw these pictures during the embodied activity of observing a ball moving and follow the ball path falling down one sacket per second at ball position passed. The third picture is the one helping them to recognize the pattern and then using it in the generalization process occurred when they had been asked to represent the motion diagram pattern of different object movies. Children described how it should be the motion pattern in three different cases: a fast animal ("gazzella" - gazelle), a slow animal ("elefante" - elephant), and a very slow animal ("tartaruga" - turtle).

Using reasoning in different contexts not directly experienced by the children is evidence of their conceptual understanding.



Consistency among representations indicates the consolidation of thought process (Bulunuz, 2013; Carey, 2000; Keil, 2011).

Non-cognitive processes were pivotal and highly relevant in the activity. Children freely participated in the proposed activity in different ways, engaging even through bodily expression. Some gestures were closely related to participation in the educational activity (clapping hands, throwing a ball, following the activity with their gaze, etc.); others were indicators of emotional involvement (satisfaction on their faces, smiles, expressions of joy).

This involvement was strongly manifested in almost all aspects of experiential learning (Glenberg et al., 2013; Gregorcic et al., 2017; Weidler and Abrams, 2014; Wilson, 2002).

The network analysis has highlighted how children activate cognitive and non-cognitive processes closely during the activity; the non-cognitive component precedes cognitive aspects and thus shapes the construction of thought processes (Taheri et al., 2019).

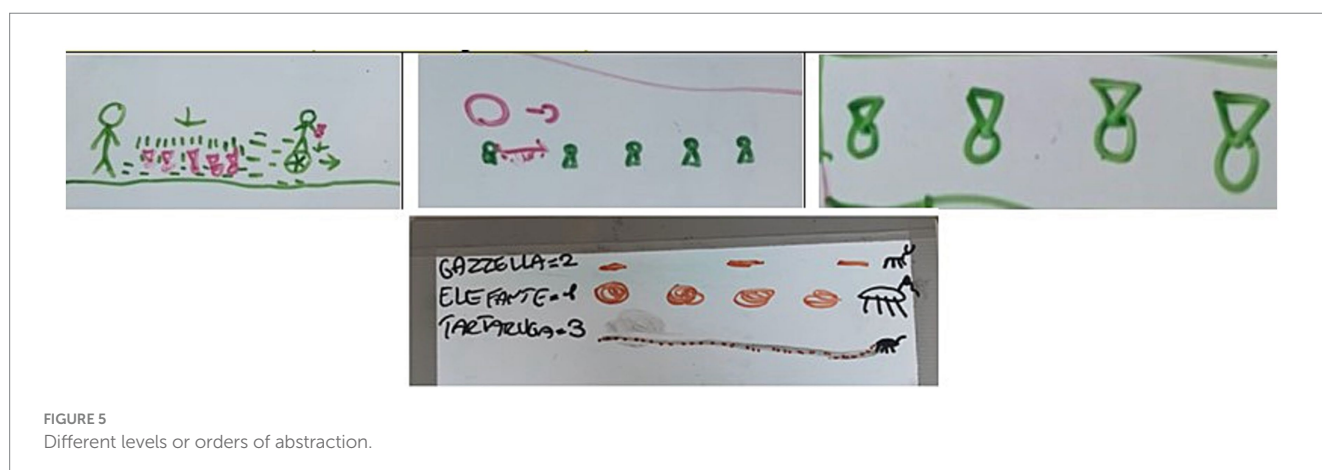
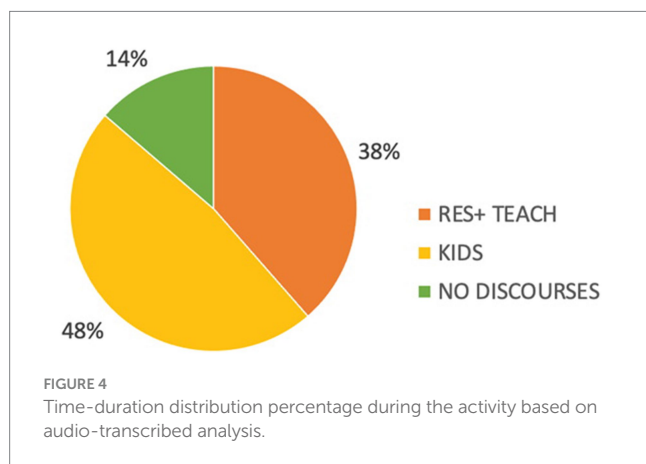
The observed interaction between teacher and students activated predominantly procedural scaffolding processes or those supporting cognitive activity. In the former case, the teacher offered simple operational instructions on starting and proceeding with the activity at different stages; they supported the children's learning process in critical moments by providing instructions on how to perform the activity or encouraged the continuation of experimentation. In the latter case, scaffolding

processes supported reasoning processes, for example, by using open-ended questions to promote cognitive activity or through inductive questions that stimulate the elaboration of experience at a more articulated conceptual level (Belland, 2017).

Furthermore, there are some noteworthy implications for instructional practices that emerge from the insights gained through this research study. Primarily, the ISLE approach has been designed to comprehensively encompass all aspects of the curriculum (Etkina et al., 2019), ensuring that each component is integrated rather than taught in isolation. This holistic design aligns closely with the core principles outlined in the National Guidelines for Italian Instruction in Primary Education, which emphasizes a unified and interdisciplinary approach to teaching/learning sciences and, in particular, physics. To effectively implement this methodology at the primary education level, it would be essential to allocate sufficient time and resources for the careful adaptation of all ISLE materials, basically designed for higher levels of instruction. This adaptation process will involve customizing lesson plans, activities, and assessment tools so they are appropriate for young learners, ensuring that the curriculum content resonates with their developmental stage and learning needs. Secondly, to promote the integration of this comprehensive pedagogical framework into teaching practices, it would be prudent to implement in-service training programs. These programs should aim to familiarize teachers with these new methodologies and equip them with the skills necessary for the adoption and implementation of ISLE, thereby ensuring the development of scientific thinking skills among their students. The lessons learned suggest that inquiry-based approaches can significantly enhance children's capacity for reasoning and abstraction, but that success depends on both the design of the environment and the sensitivity of the scaffolding provided by teachers.

6 Conclusion and limitation

The processes of children's scientific thinking involve complex cognitive activity, which can be activated and expanded when learning environments promote active, collaborative construction of knowledge. Children are capable of exploring scientific concepts and



gradually building increasingly abstract and sophisticated understanding (Bulunuz, 2013; Carey, 2000; Keil, 2011).

This development follows a cyclical, not linear, path: children observe, experiment, hypothesize, and use abstract concepts to guide further inquiry. Learning progresses according to the rhythm of their reasoning rather than through fixed stages (Kolb, 1984; Zull, 2002).

Inquiry-based teaching encourages students to explore phenomena, formulate hypotheses, and share ideas. Teachers do not provide memorized procedures but foster exploratory attitudes, reasoning, and investigative methods. Students are invited to analyse situations from multiple perspectives, seek solutions, and use divergent thinking. Critical and creative thinking is thus valued, showing that knowledge can be reached through multiple routes (Chinn and Malhotra, 2002).

Learning occurs when students actively construct knowledge and reflect on their reasoning. What they report having learned stems not from information given but from what they have processed and discovered (Bruner, 1990). Teachers provide scaffolding by adjusting support flexibly throughout activities, guiding without replacing children's efforts (Van de Pol et al., 2015).

Cognitive processes are also intertwined with emotional and motivational aspects. Embodied cognition highlights how bodily interaction with the world shapes thinking, underscoring the value of movement and sensorimotor experience in development (Glenberg et al., 2013; Wilson, 2002). Approaches like ISLE leverage body and emotion as resources, broadening opportunities for learning (Gregorcic et al., 2017).

A primary limitation of this study lies in its focus on a single classroom activity as the basis for analysis. While this activity was implemented multiple times under comparable conditions and with similar pedagogical objectives, only one iteration was subjected to detailed examination. Consequently, the findings may not fully capture the breadth of children's responses or the nuances of their developing scientific reasoning skills across different sessions. Future research would benefit from the inclusion of longitudinal data or the systematic analysis of multiple activity instances to more comprehensively trace the emergence and consolidation of reasoning patterns and cognitive skill development in young learners.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The requirement of ethical approval was waived by the Ethics Committee Regulation of the University of Trieste, <https://www.units.it/ricerca/etica-della-ricerca>. The schools joined the project by signing a research protocol outlining the research phases. Schools provided detailed information about the research activities to the families of the participating children, and required their authorization for participation was requested. The studies were conducted in accordance with the local legislation

and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

CB: Writing – original draft, Writing – review & editing. VB: Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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