Chapter # 28

FOSTERING SCIENTIFIC THINKING IN PRIMARY STUDENTS THROUGH INVESTIGATIVE ENVIRONMENT

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ABSTRACT
The Agenda 2030 objectives highlight the need to engage students in STEM (Science, Technology, Engineering, and Mathematics) to support ecological and cultural transitions. Understanding students' scientific thinking involves examining their social, cultural, and environmental contexts. Inquiry-based learning is an effective teaching strategy that promotes exploration and develops scientific reasoning.
This work presents preliminary findings from a case study testing innovative teaching methods to inspire primary school students in STEM. In the first phase, a class of final-year primary students participated in a hands-on physics activity using an inquiry-based approach. Observations indicated that the activity improved reasoning flexibility, encouraged collaborative learning, and increased motivation and engagement.

Keywords: STEM, scientific thinking, inquiry-based, scaffolding, collaborative learning.

1. INTRODUCTION

The international debate on education in recent years has certainly paid a lot of attention to the importance of promoting STEM (Science, Technology, Engineering, and Mathematics) disciplines in schools from the early years of the education path (ONU Agenda 2030; European Commission, 2018).

Science education is a fundamental aspect in the development of both disciplinary and transversal skills (such as creativity, critical thinking, and reasoning skills) that can promote citizenship skills (i.e. social, economic and environmental skills) (Edwards-Schachter, García-Granero, Sánchez-Barrioluengo, Quesada-Pineda, & Amara, 2015; Amos & Levinson, 2019; Karamustafaoğlu & Pektaş, 2023). The new generations will increasingly live with scientific discoveries and related technological transformations. Therefore, thinking about learning paths that respond to emerging educational needs is essential. Students must develop skills to participate in discourses that incorporate scientific concepts and be able to evaluate the argumentations involved critically.

It becomes fundamental to assume a theoretical and methodological perspective on which to base the learning paths of STEM disciplines. This will support the development of scientific thinking and the capacity for hypothetico-deductive, inductive, and analogical reasoning, increasing the ability to use critical thinking to understand reality.

The socio-constructivist perspective can represent a valid theoretical framework of reference as it considers learning a knowledge construction process in which the learner plays an active and creative role (Fleer, 2021). This educational approach favours participatory forms of learning, stimulating children's initiative and sharing and collaborating with peers.

Interaction becomes central in the learning process, both with respect to the relationship between peers and the relationship between teacher and students.

The role of the teacher in this process is to provide a "support structure" or "scaffolding", which sustains the children's learning process by helping them to acquire a higher level of skills than they initially possessed (Bruner, 1976; 1990; Belland, 2017; Hsu, Lai, & Hsu , 2015; Lee & Tee, 2021; Shin, Brush, & Glazewski, 2020) and stimulate reflection, reasoning and argumentation through innovative teaching strategies. Among these, the "inquiry-based learning" approach can represent a suitable methodology for facilitating and encouraging the development of scientific thinking in children, as it places inquiry at the center of the learning process (Worth & Grollman, 2003; Krogh & Morehouse, 2020). The teacher encourages free exploration and experimentation by the children of a particular scientific phenomenon, invites them to ask questions and share them with the group; the teacher participates in the process of building knowledge, welcomes their reflections and helps them structure more advanced and complex forms of argumentation.

2. THE INQUIRY-BASED APPROACH

The term “inquiry” precisely describes the investigation, the action that characterises the scientist's work. The scientist investigates reality to understand its phenomenology, identify causes, and find relationships. His action is concrete and is articulated in continuous training to observe by experimenting with techniques and methodologies that make his investigation increasingly accurate and precise.

Referring to the model proposed by Worth & Grollman (2003), learning based on inquiry is characterised by different phases. Initially, children explore the phenomenon and the materials proposed for exploration. They put themselves to the test by experimenting, through play, what they can do and how they can do it. At the same time, they formalise their exploration by formulating questions and freely sharing ideas among peers and teachers. Questions are the antechamber of the argumentation process. They induce reflection and planning of the exploratory activity. This phase alternates with a more guided and structured one by the teacher. Inquiry is always at the centre of the action. Still, the process gradually develops to enable the child to try more targeted explorations that allow him to make predictions, plan results, and collect and record even simple data.

2.1. The Role of the Teacher in Learning Processes Based on Inquiry

The teacher takes on the role of mediator in the process of facilitating inquiry and promoting it as a learning style in the child through scaffolding processes (Brown & Palincsar, 1989; Cobb, Yackel, & Wood, 1992; Collins, Brown, and Newman, 1987; Strat, Henriksen & Jegstad, 2024). The teacher supports the child's instinctive predisposition to inquiry. The teacher does not guide the child to acquire knowledge but to construct knowledge according to the scientist's own style.

"Scaffolding" is a metaphor used to explain the role of the adult in child-centred education. Introduced by Bruner and colleagues in 1976, this concept illustrates how an adult supports and guides a child during an activity. Rather than simplifying the task, the adult assists the child in developing skills beyond their capabilities through shared interpersonal interactions. Acting as a scaffold, the adult offers support, sustenance, and encouragement as the child navigates through the complexities of the activity.

In this approach, the adult doesn't just teach the child how to complete the activity. Instead, they engage with the child in diverse ways, responding to their actions and thoughts. By complementing the child's efforts, the adult provides dynamic support that encourages the child's interest, keeps the activity's complexity in focus, aligns with the activity's objectives, guides the child in learning proper actions, and assists the child in reflecting on their thought process and regulating the activity.

According to Bruner and colleagues, the task is not simplified, but the child is not alone in performing it. This allows the child to develop competencies above individual performance level but shared on the interpersonal plane. The adult acts as a scaffold, an existing structure that supports, sustains, and promotes the child in climbing up the complexities of the ongoing situation.

The adult does not simply teach the child how to perform an activity but interacts with the child in very different ways, each sensitive to the child's actions and thoughts (Asy'ari, Ikhsan, & Muhali, 2019; Cruz-Guzmán, García-Carmona, & Criado, 2020). By complementing the child's initiatives, the adult offers dynamic support that:

- promotes the child's interest in the activity;
- maintains the complexity of the activity in sight;
- is oriented towards the intended objective of the activity;
- guides the child to learn how to act properly;
- supports the child in reflecting upon her/his thinking process and regulating the activity.

2.2. The Process of Thinking

In inquiry-based teaching, the emphasis placed on building an idea is a fundamental element in promoting meaningful and lasting learning. This teaching approach stands out because, instead of focusing solely on the correctness of answers, it values the path that leads to the formation of ideas, promoting creative thinking and the development of argumentation skills (Kuhn, Black, Keselman, & Kaplan, 2000).

In a traditional educational context, children often learn to search for the "right" answer to meet teachers' expectations. However, this method can limit intellectual exploration and inhibit children's natural curiosity. On the contrary, the inquiry-based approach encourages children to see the learning process as a continuous exploration, where each hypothesis formulated is considered valuable, regardless of its outcome. This allows children to develop a positive attitude towards science and knowledge since they feel free to experiment, make mistakes and correct themselves without fearing judgment.

Allowing children to confirm or refute their hypotheses, often unique and deeply personal, is essential for developing critical thinking. Testing their ideas strengthens their reasoning skills and helps them understand that knowledge is a constantly evolving construct. Valuing these hypotheses, therefore, becomes the first step in ensuring that children develop confidence in their cognitive abilities and consider science a field open to investigation and discovery.

In this context, the teacher's role is crucial. Instead of providing immediate answers, the teacher should adopt a dialogic approach, responding to children's questions with further questions that stimulate reflection. The teacher should encourage children to search for answers within themselves, formulate new hypotheses, and explore different possibilities. In this way, critical thinking is activated and nourished as children learn to evaluate and reconsider their ideas, developing greater intellectual autonomy (Lee & Tee, 2021).

Furthermore, the inquiry-based approach encourages peer collaboration and comparison, where ideas are discussed and argued collectively. This improves children’s communication skills and prepares them to work in teams, consider different perspectives, and build knowledge cooperatively. In an environment that values idea-building, children learn that the learning process is not linear but a journey whole of exploration, reflection, and discovery (Chen, 2021).

3. DEVELOP SCIENTIFIC THINKING THROUGH EMBODIED INVESTIGATION

According to Jonassen, Marra, and Palmer (2004), learning environments that are designed according to a socio-constructivist perspective differ from traditional teaching approaches because they offer multiple representations of reality that reflect the complexity of the world; they encourage active knowledge construction by students, propose authentic and meaningful tasks, connected to children's experience and the real world; they encourage reflection, reasoning and collaborative forms of learning, where negotiation rather than competition is encouraged.

The learning environment should be built to stimulate investigation and encourage children's active participation and direct experience. Traditionally, the frontal methods of teaching have resulted in learning practices in which communication in the classroom is based on sitting students, where the teacher frames the topic and sets the pace of the lessons, encouraging students to express their opinions and ask questions, but always remaining in a static position. According to this view, using movement and bodily experience is not considered a factor connected to the learning process. Thought processes are closely linked to cognitive processes but less to sensorimotor processes. It follows that teaching does not encourage children's movement in the classroom and does not incorporate it into the learning experience, instead supporting the importance of maintaining a sitting position in class, considered a good indicator of the ability to concentrate and focus on the task.

However, the studies that have developed the theme of embodied cognition undermine this traditional conception, highlighting the central value of bodily experience in the process of building knowledge. Based on the theoretical framework of bodily cognition, action and perception are inextricably linked: the sensorimotor experiences derived from the environment contribute to grounding the cognitive processes (Glenberg, Witt, & Metcalfe, 2013; Danish, Enyedy, Saleh, & Humburg, 2020; Dove, 2022).

Therefore, the thinking process can be built starting from children's concrete experiences in learning contexts since cognitive aspects and sensorimotor processing are closely linked (Wilson, 2002). Scientific evidence has highlighted a correlation between activities such as observation, simulation of other people's gestures and imitation and the activation of brain areas central to learning (Rizzolatti & Craighero, 2004; Meister et al., 2003). For example, some studies highlight how attention and memory improve when using hands are associated with learning (Weidler & Abrams, 2014). Other studies support evidence that highlights the positive effects of movement and the use of gestures in learning mathematics (Riley, Lubans, Holmes, & Morgan, 2016).

This evidence underlines how learning processes can be supported by practical experience and how theoretical STEM concepts can be understood more easily by designing learning environments that involve experimentation through the use of the body and movement (Schmidt et al 2019).

4. OBJECTIVES

In this work, we will present some preliminary data from a case study that aims to experiment with innovative pedagogical models to stimulate the interest of children in primary school in scientific reasoning of STEM disciplines. The first phase of the project involved a class of pupils attending the last year of primary school who participated in an educational experimentation activity on learning physics based on an inquiry-based learning approach.

5. METHODS

A fifth class of primary school (composed of 10 children) participated in the investigation. The activity proposed to the children concerned the motion in one dimension (introduction to the study of kinematics in Physics, description of motion and its patterns) and took place in 2 meetings for at least 3 hours. These features sampled what was needed for conducting a case-study research design (Creswell & Poth, 2017).

The activity was prepared together with the teacher according to an inquiry-based approach and was characterised by the following aspects:

- Structuring student-centered learning environments;
- Learning process based on active learning;
- Centrality of student participation to encourage a process of knowledge construction.

These three aspects were shaped using the Investigative Science Learning Environment (ISLE, Etkina, Brookes, & Planinsic , 2019) approach. The ISLE process guarantees that it will fulfil the aspects we require for our activity design (Brookes, Etkina, & Planinsic, 2020). This is a crucial methodological point in conducting our research: the content design has to be thought in a well-defined disciplinary framework to ensure we achieve research outcomes. An ISLE-based learning activity is an authentic inquiry experience where children learn Physics by mirroring scientists' practices (Etkina et al., 2019; Brookes et al., 2020). In making science, children are engaged in scientific cognitive processes: the same ones they need to develop scientific abilities (Etkina et al., 2006). Furthermore, the teaching/learning ISLE sequence is designed in order to activate and connect different brain areas, providing a complete cognitive learning cycle (Etkina et al., 2019; Zull, 2004; Weidler & Abrams, 2014), enhancing embodied cognition (Schmidt et al 2019; Gregorcic, Planinsic, & Etkina, 2017).

The children's learning experiences were video recorded; then, all the videos were transcribed, and the transcriptions were used as a starting point for the analysis's insight. The transcribed dialogues have been framed into clustering of discourse sequences, which should recognise a particular structure, depicted using vignettes (Skilling & Stylianides, 2020), like snapshots from the video frames.

The analysis of the vignettes highlighted the learning and thinking processes that the children developed during the teaching experience. The purpose of the analysis of the contents of the vignettes was to identify significant aspects of the process of scientific thought formation, linking them to the participation processes and the structure of the learning environment. Specifically, the following indicators were considered: the different levels in the scaffolding process, the construction phases of the scientific thinking process (in terms of reasoning), and the emotional/motivational aspects (in terms of embodied engagement).

6. RESULTS

This section will highlight the main results analysing our video transcription files. The vignettes presented here focus on representative features of the entire scenario in the classroom activity. We underpinned the main processes we investigated for each selected vignette in this study. We selected the ones who led us to the processes involved, from the teacher's point of view, examining the scaffolding strategy and the children's standpoint in reasoning and embodying epistemic practices.

In Vignette #1 (Figure 1), the activity involves pulling a ball along a defined path, marking its progress with sand packets that fall as the ball moves. At the same time, a metronome pulses at 60 BPM on the interactive whiteboard. Scaffolding is provided through procedural tips for effectively setting up and executing the activity. Throughout the activity, the teacher actively engages students in reasoning processes. This is done by guiding them to observe and analyse the patterns that emerge as the ball moves along the path, such as the timing of the sand packets falling or the rhythm set by the metronome.

All students are actively involved in the learning experience, playing various roles that allow them to embody the activity.

The Vignette #2 (Figure 2) allows us to emphasise the richness of the process. From the scaffolding strategy, the teacher continues to encourage children's engagement through procedural scaffolding, guiding how to pull the ball, beat time, and observe patterns. As students become more familiar with the task, they change their roles, and thus perspectives. Over time, the scaffolding is gradually reduced; children take more responsibility and develop self-empowerment in conducting the activity independently. This fosters their autonomy and confidence in the activity development. During this time, reasoning processes are activated: children recognise patterns and make cognitive connections, observing space-time relationships between the speed of the ball (slow or fast) and the number of sand packets falling (more or fewer). The teacher reinforces these conceptual connections through repetition and variation.

Figure 1.
Vignette #1: starting activity, finding patterns.

As students progress, their reasoning becomes more sophisticated. This happens while children are engaged in a highly physical learning experience involving movements such as pulling the ball, clapping hands, stepping feet, and repeating time aloud. This "embodied measurement" helps students internalise abstract concepts through physical actions. As they collaborate and exchange roles, students experience different facets of the activity, enhancing their understanding through sensory and kinesthetic experiences. The process culminates in developing an "embodied technique," where students perform the activity with confidence and fluency.

In Vignette #3 (Figure 3), a new process step starts. The teacher provides procedural recommendations to guide children towards articulating their observations verbally. This begins with prompting students to describe their actions, the materials they are using, and the outcomes they are observing. The teacher also facilitates group discussions, encouraging students to build on each other's ideas. Reflection is activated as part of the reasoning process. As students speak, their gestures and movements complete their words, furnishing a fuller profiling of their cognitive loading of new information. This physical engagement is instrumental in making abstract ideas more available, as it helps to anchor their verbal representations in concrete, sensory experiences, according to the experiential learning cycle (Zull, 2004). Children use their hands to illustrate the movement of an object, point to specific facets of their activity, or mimic actions that embody the concepts they are discussing.

Figure 2.
Vignette #2: repeating trials.

The Vignette #4 (Figure 4) exhibits the time for the visualisation process of drawing sketches. This activity is designed to enhance student's ability to represent their observations through drawing, blending visual thinking with verbal and physical engagement to create coherent representations of real-world phenomena. The teacher provides reinforcement to guide children towards creating pictorial representations of their experience. Initially, the teacher helps students translate their observations into visual layout, improving their capability to communicate complex ideas through simple sketches. Drawing and sharing these visual representations activates reasoning by encouraging students to conceptualise a coherent depiction of real scenario.

Figure 3.
Vignette #3: verbalisation time.

Vignette #5 (Figure 5) shows the activity designed to evaluate the consistency between different types of representations - verbal descriptions and sketches - by engaging students in collaborative reflection. The teacher supports students in evaluating the consistency between their verbal and pictorial representations. The working group is now fundamental: this peer-to-peer evaluation enhances understanding and promotes active listening and productive feedback. Through this evaluation process, students learn to refine their thinking and improve their representations. The embodied aspect of this activity involves students working in groups, standing around the whiteboard or large paper surfaces, actively pointing, gesturing, and using their bodies to draw attention to specific elements of their sketches or verbal explanations. As they discuss, they may use hand movements to trace the path of objects, point out differences, or highlight particular areas of the drawing. words and sketches, students enhance their critical thinking and metacognitive skills, while the creation of a shared artifact reinforces collaboration, communication, and the integration of diverse perspectives into a unified representation.

Figure 4.
Vignette #4: drawing time.

Vignette #6 (Figure 6) shows the last scenario of the activity done. This activity stage focuses on communicating using a combination of verbal descriptions and pictorial representations. The teacher promotes time for storytelling and group discussions. Each group present their representations. The teacher also encourages active participation from all students by prompting them to listen carefully, and provide constructive feedback. Verbalization becomes a key tool for the reasoning process. As children describe their sketches using spoken language, they must clarify their thinking and make explicit the connections between their visual and verbal representations. This process of verbalization helps them articulate their understanding, find gaps in their reasoning, and refine their interpretations based on group feedback.

Through dialogue, students justify their choices and explain the reasoning behind their representations. Promoting deeper engagement with the material encourages them to think critically about how different forms of representation can effectively convey meaning. For instance, they may discuss why a certain shape represents a concept or how a particular color in the sketch conveys a specific idea. These discussions help students internalise that representations are passive displays and active tools for communicating complex concepts.

Figure 5.
Vignette #5: group discussion time.

Gestures play a significant role in complementing verbal explanations and enriching overall communication. When students showcase their sketches, they employ expressive hand movements, body language, and facial cues to emphasize particular elements of their drawings, direct the audience's focus to specific details, and communicate subtleties that verbal expression alone may not fully convey. Combining spoken explanations, visual illustrations, and physical gestures helps all students better understand and connect with the information. When students discuss their ideas in a group, they improve their understanding and add to what the whole class knows. During each presentation, students have the opportunity to engage in reflection, compare their approaches, consider alternative perspectives, and refine their thinking based on the insights provided by their peers.

Figure 6.
Vignette #6: communication time.

5. DISCUSSION AND CONCLUSION

This study highlights how innovative teaching methods can enhance scientific reasoning in STEM fields, especially through embodied, inquiry-based learning. The activities demonstrate the benefits of integrating physical experiences into learning to boost cognitive development, conceptual understanding, and engagement in young learners.

The learning environment based on the ISLE framework (Etkina et al., 2019) effectively balanced scaffolding and independence. This approach allowed students to shift between experiential learning and conceptual reasoning. Students gained a multi-modal understanding of physical concepts through activities like pulling the ball, observing patterns, and sketching their observations. These results support research on the link between sensorimotor processes and cognitive functions (Glenberg et al., 2013; Schmidt et al., 2019).

This research aims to provide insights into two key points of interest deserving of in-depth exploration: the development of scientific thinking through embodied practices and the scaffolding and collaboration processes as catalysts for learning.

Concerning the development of scientific thinking, this study tries to contribute to validating how embodied cognition enhances learning. Physical activities like handling objects and gestures helped students connect abstract concepts to real-world phenomena. This was evident during "embodied measurement" and "drawing time," where students internalised concepts through sensory interactions. During group discussions, children used gestures and actions to support their explanations, reinforcing that physical movement enhances verbal and visual communication. These strategies fostered metacognitive skills as students reflected on their reasoning and adapted explanations based on peer feedback. Integrating movement into learning challenges traditional classroom methods, providing evidence of the benefits of combining cognitive and bodily engagement. (Rizzolatti & Craighero, 2004; Weidler & Abrams, 2014).

The teacher's scaffolding strategies were crucial in building student autonomy. Initially, they offered procedural guidance and encouraged role-switching, ensuring active participation and diverse perspectives. As students familiarised themselves with the task, support was gradually reduced, promoting independence and confidence. This withdrawal of support aligns with socio-constructivist principles of active participation and knowledge co-construction (Jonassen et al., 2004). Indeed, Collaboration has become an essential aspect of the learning process. Engaging in group discussions and peer evaluations enabled students to practice negotiation and collaborative problem-solving, enhancing the social aspect of scientific reasoning. These collaborative activities helped students sharpen their individual insights while also adding to the class's collective knowledge. This supports previous research highlighting how collaboration fosters critical thinking and deeper understanding. (Brookes et al., 2020).

These two aspects present some actionable implications for STEM education. The first concerns integrating embodied learning as an accessibility tool for content-driven abstract concepts in primary education. The second concerns encouraging students to express their understanding through multiple representations as a reasoning tool for critical thinking development. The last concerns enhancing understanding and fostering a collaborative learning culture through group work and peer feedback in the context of dynamic scaffolding teacher support.

This study highlights the value of innovative, embodied, and inquiry-based approaches to STEM education. By linking sensorimotor experiences to cognitive processes, fostering collaboration, and emphasising multi-modal communication, the learning environment successfully supports the development of scientific reasoning in young learners. These findings reinforce the importance of designing interactive, student-centred activities that reflect the complexity of real-world phenomena while making learning both meaningful and engaging. Future research could expand on this preliminary work by exploring the long-term impact of embodied learning approaches across diverse STEM topics and evaluating their scalability in larger classroom settings.

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