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# HOW TO DEVELOP SCIENTIFIC THINKING IN PRIMARY STUDENTS BY INVESTIGATIVE ENVIRONMENT

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## Abstract

The objectives of the ONU Agenda 2030 (designed to accompany schools in the ecological and cultural transition) 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. 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). Among innovative teaching strategies, the "inquiry-based learning" approach can represent a methodology suitable for stimulating the development of scientific thinking in children, as it places inquiry at the center of the learning process (Worth & Grollman; 2003; Belland, 2017). 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. The analysis of the data collected, using observational tools, highlighted that the activity has stimulated the flexibility of reasoning; children have built knowledge collaboratively and have shown a high motivational involvement.

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

## 1. Introduction

The international debate on education during recent years has certainly paid a lot of attention to the importance of promoting STEM (Science, Technology, Engineering and Mathematics) disciplines in schools right from the early years of the education path (ONU Agenda 2030[1]; European Commission, 2018[2]).

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 et al., 2015). The new generations will increasingly find themselves living with scientific discoveries and related technological transformations, and it is, therefore, essential to think about learning paths that respond to emerging educational needs. It is critical that students develop skills to participate in discourses that incorporate scientific concepts and be able to evaluate the argumentations involved critically.

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

The socio-constructivist perspective can represent a valid theoretical framework of reference as it considers learning as a knowledge construction process in which the learner plays an active and creative role (Fleer, 2021). This educational approach favours participatory forms of learning, which stimulate the initiative of children, sharing and collaboration between peers. The aspect of interaction therefore becomes

[1] Transforming our world: the 2030 Agenda for Sustainable Development. https://sdgs.un.org/2030agenda
[2] European Union (2016). *STEM skills for a future-proof Europe: Fostering innovation, growth and jobs by bridging the EU STEM skills misma*tch. EU Stem Coalition.

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, 1990; Belland, 2017; Hsu et al., 2015; Lee & Tee, 2021) and stimulate reflection, reasoning and argumentation through innovative teaching strategies. Among these, the "inquiry-based learning" approach can represent a suitable methodology for stimulating the development of scientific thinking in children, as it places inquiry at the center of the learning process (Worth & Grollman, 2003). 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. Develop scientific thinking through embodied investigation

According to Jonassen et al. (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 therefore 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, the use of movement and bodily experience is not considered a factor connected to the learning process. Thought processes have been considered closely linked to cognitive processes but less to the 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).

Therefore, the thinking process can be built starting from concrete experiences that children have 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 that are central to learning (Rizzolatti & Craighero, 2004; Meister et al., 2003). For example, some studies highlight how attention and memory improve when the use of the hands is associated with the learning process (Weidler & Abrams, 2014). Other studies support evidence that highlights the positive effects of movement and the use of gestures in learning mathematics (Riley et al, 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).

## 3. 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.

## 4. 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 et al., 2019) approach. The ISLE process guarantees that it will fulfil the aspects we require for our activity design (Brookes et al., 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; Brooke 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 et al., 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).

## 5. Results

In the following table, we report an extract of the analysis conducted. This is a sequence of the entire activity we analysed. The extract should show how we collected information about the indicators we were investigating. Here, eight examples are presented: this sequence is representative of many others, as meaningful for the learning process they depict in terms of scaffolding, reasoning, and embodying.

*Table 1.*

| **Vignette** | **Learning sequence** | **Process Indicators** | | |
|---|---|---|---|---|
| | | **Scaffolding** | **Reasoning** | **Embodying** |
|  | Pulling a ball, following the path using sand packets falling down while the ball passes, listening to the metronome pulsing at 60 BPM (on the interactive whiteboard) | Procedural tips for carrying out the activity, preparing the learning environment | Activating reasoning processes by teacher's guidance; finding patterns for generating analogies | All kids are actively engaged playing different roles and embodied the activity: immersive and exploratory characters |

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|---|---|---|---|---|
|  | Repeated trials of pulling the ball, beating the time, observing the patterns | Encouraging children's engagements, enacting procedural scaffolding. | Recognising patterns and a space-time relation, making cognitive connections (slow-fast ball, more or fewer packets). | Moving arms, clapping hands, and stepping feet for "embodied measurement" of the time repeating aloud |
|  | | Guiding children in changing roles during the activity, reinforcing. | | Collaborating process, exchanging roles. |
|  | | Removing procedural scaffolding, improving children's self-empowerment in conducting the activity alone. | Reinforcing conceptual building and achieving conceptual stability | "Embodied technique" in conducting the activity |
|  | Describing using words what observed | Procedural tips for guiding children towards verbal representation enhancing discussion | Activating reflection as part of reasoning process (internalization) | Embodied attention, gestures for explaining ideas while speaking |
|  | Representing drawing a sketch what observed | Procedural tips for guiding children towards pictorial representation, sharing ideas | Conceptualizing coherent representation of real facts and generated ideas (externalization) | Immersive postures controlling the writing process on whiteboard |
|  | Discussing to match and evaluate consistency between representations by words and sketch | Procedural tips for guiding children towards evaluating processes of different representations | Reasoning based on searching consistency and activating evaluation process | Artifact realised shared by children's group |
|  | Communicating and presenting by words pictorial representation | Promoting time for telling and discussing all together, sharing representations | Verbalisation as the tool for giving reason and sense making between different representations | Gestures indicating the meaning of sketches described using spoken language |

## 6. Discussion and conclusions

The analysis of the data collected, using observational tools, highlighted that the activity:

- has stimulated the flexibility of reasoning;

- The children have built knowledge collaboratively through the transition between experiential and conceptual levels and have shown a high motivational involvement;

- The scaffolding processes were supported by the structure of the activity itself and the organization of the learning environment.

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