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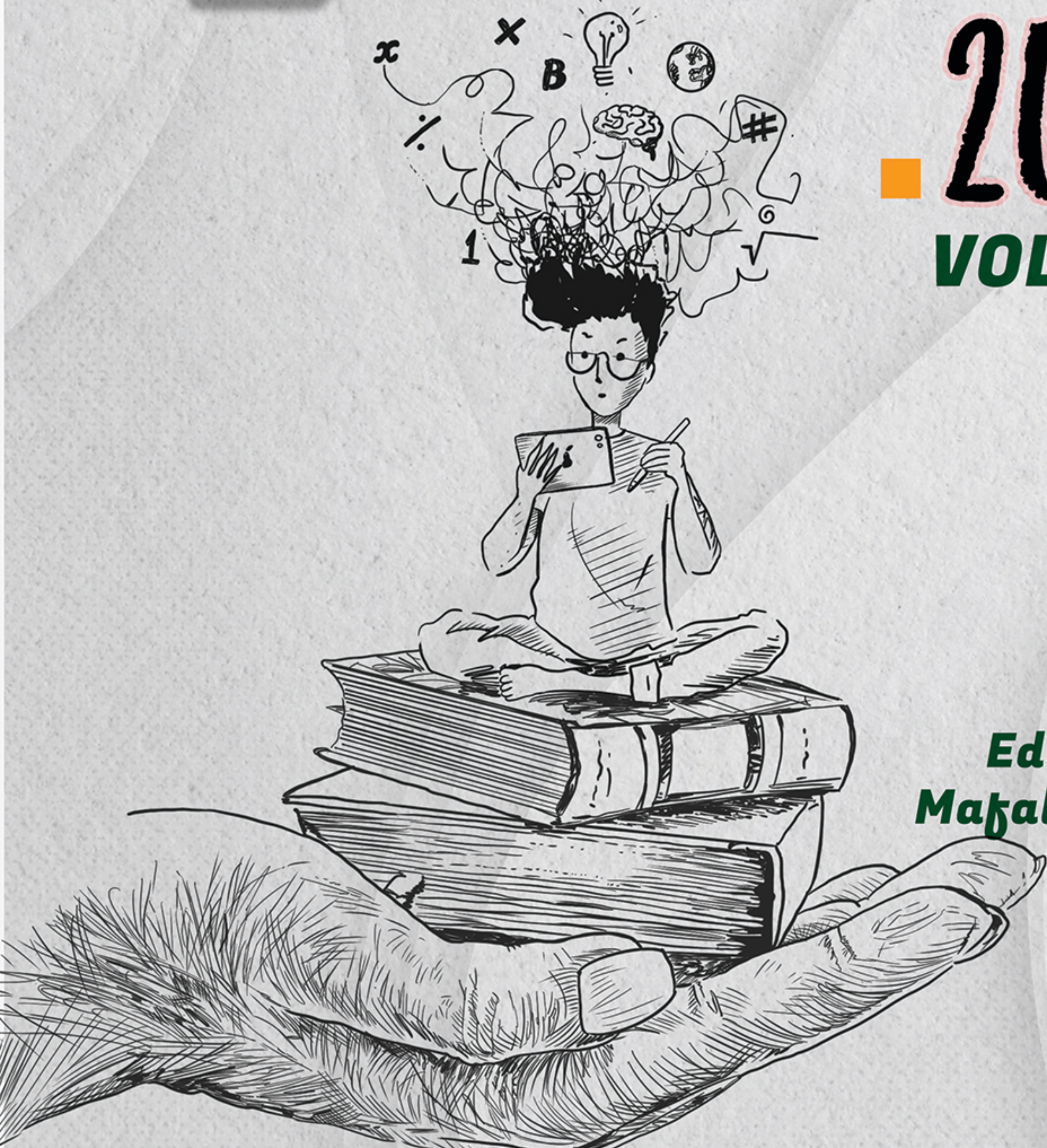

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REASONING THROUGH REPRESENTATION: THE ROLE OF DRAWING IN MODEL CONSTRUCTION IN PRIMARY PHYSICS

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Abstract

This study investigates the epistemic role of drawing in primary science classrooms, conceptualizing it as a semantic tool that mediates the transition from concrete experience to abstract conceptualization. Building on socio-constructivist and multimodal perspectives, drawing is framed not as a mere representational outcome but as a generative semiotic practice through which children externalize, negotiate, and reorganize their emerging scientific models. Our classroom-based research in primary physics education shows that drawing operates as a proto-modeling device: it enables students to move from what has been described as "physical babbling" toward progressively structured explanatory systems. In this process, the pictorial register functions analogously to its documented use in early algebra, where visual representations support the shift from arithmetic reasoning to relational and structural thinking. In both domains, drawing sustains reasoning through representation—where conceptual insight emerges in the act of inscription—and reasoning from representation—where the produced artifact becomes an object of collective reflection, revision, and validation. We observed that the pictorial medium supports children in managing the dual epistemic demands of correspondence (alignment with observed phenomena) and coherence (internal consistency within the emerging representational system). Intellectual realism frequently characterizes these productions, as students depict not only what they see but what they consider conceptually relevant. In this sense, drawing functions as a conceptual change strategy: it renders implicit models visible, making intuitive ideas and resources available for discussion and restructuring. At the same time, our analysis highlights potential didactic pitfalls, including procedural reductionism (where drawing collapses into task reproduction) and semiotic hybridization without shared conventions, which can hinder model stabilization. The findings therefore, underscore the need for intentional multimodal orchestration across pictorial, verbal, and symbolic representations. When pedagogically scaffolded, drawing becomes a powerful ontological disambiguator and a central mediator in the construction of robust scientific knowledge in primary education.

Keywords: *Scientific reasoning, drawing, semantic tool, physical babbling, multiple representations.*

1. Introduction and theoretical framework

Drawing is not only a fun activity for children but also a crucial form of non-verbal communication (Longobardi et al., 2022). Children's drawings have attracted research from various perspectives: psycological, pedagogical, and educational.

Psychologically, they reveal inner worlds, emotions, and perceptions beyond realism (Bozzato et al., 2021; Kallitsoglou et al., 2022); more recently, research has increasingly emphasized their use as for developmental and diagnostic potential (Jensen et al., 2023).

Pedagogically, drawings are valuable tools for understanding children's conceptions, as they reveal how children represent their internal ideas visually (Ehrlén, 2009). Piaget and Inhelder (1966/1969) characterized children's representation as a semiotic function - the ability to depict a signified entity through a signifier. They distinguished between symbols, which have a meaningful link to what they represent, and signs, which are arbitrary, conventional signifiers. Symbols are created by the individual child, while signs are collective and conventional. Luquet (2001) identified different methods of representation in children's drawings. A *visually realistic* picture resembles a photograph, depicting objects from a single perspective. In contrast, an *intellectually realistic* picture emphasizes key characteristics, regardless of perspective, using techniques such as transparency, plan view, folding out, or mixed viewpoints to represent parts of an object that cannot be seen from just one angle.

Thomas (1995) contended that children's drawings do not necessarily mirror internal thoughts or visual impressions. Conversely, Goodman (1976) explained that illustrations are based on universally accepted symbols, similar to words, highlighting that a resemblance between a picture and an object is not necessary for it to serve as a representation; what matters most is that the image refers to the object.

Ehrlén (2009) proposed that when drawings are combined with children's verbal descriptions of their ideas and understanding (such as in Vosniadou & Brewer, 1992), these visual and verbal tools may serve complementary roles, functioning either to enhance each other's effectiveness or as tangible, concrete reference points that facilitate discussion and deeper exploration of the children's conceptions. In this way, drawings become a tool for children to facilitate their conceptualization. Then, children's drawings are understood within the context of pictorial conventions, while their conceptions are seen as embedded within conceptual frameworks. Children use drawings to develop their scientific conceptual understanding, representing their ideas in specific situations (Vosniadou, 1994; Halldén, 1999; Ehrlén, 2009). In science education, children's drawings are increasingly seen as tools because they help young learners understand and communicate scientific ideas through different ways of representation (Monteira et al., 2024). Not only supporting children's understanding (Ehrlén, 2009; Vosniadou & Brewer, 1992), drawings allow children to express observations, relate everyday experiences to scientific concepts, and engage in disciplinary practices (Areljung et al., 2022), as well as scientific reasoning (Yoon et al., 2021). This leads drawings to acquire an epistemic role in science education, mainly in inquiry-based activities and guided talks, encouraging group reasoning, reflection, and discussion (Ainsworth et al. 2011, Yoon et al., 2021; Areljung et al., 2025).

Building on socio-constructivist and multimodal perspectives (Kress, 2009), the aim of our study is to investigate the epistemic role of drawing in primary science classrooms, conceptualizing it not as a mere representational outcome, but as a generative semiotic practice and semantic tool that mediates the transition from concrete experience to abstract conceptualization (Ainsworth et al., 2011; Prain & Tytler, 2012; Monteira et al., 2024). Through this lens, drawing is framed as a foundational process of transduction through which children externalize, negotiate, and reorganize their emerging scientific models (Kress, 2010; Brooks, 2009; Leopold & Leutner, 2012; Kampeza & Delserieys Pedregosa, 2024). To investigate these aspects, our research questions were as follows:

- How do primary students utilize drawing to process the epistemic demands of correspondence to observed phenomena and internal representational coherence?
- In what ways does the act of drawing function as a conceptual change strategy by externalizing and restructuring students' implicit mental models and ideas?

2. Methodology

This study uses a case study based on cognitive ethnography, which explores how children cognition, like representational reasoning, develops within cultural settings such as classrooms. While traditional ethnography examines broad social patterns, cognitive ethnography shows how drawing functions as a disciplinary reasoning tool (Ball et al., 2000; Nersessian, 2006). Viewing the classroom as a discourse-based environment, we observe how children use pictorial signs to assume 'epistemic roles' for scientific modeling. In this way, we move beyond the individual "mind-as-container" model to examine cognitive processes as distributed and situated activities. This framework is particularly suited for studying drawing, as it allows for the analysis of how mental models are externalized and restructured through interaction with mediating artifacts (Ainsworth et al, 2011). To capture these micro-scale cognitive shifts, this methodology integrates specialized analytical tools from the cognitive sciences, like micro-discourse analysis, video-based interaction analysis, cultural model analysis and trace analysis. This multi-layered analytical approach ensures that drawing is investigated not as a static product, but as a dynamic, generative practice through which scientific thinking is socially and materially constituted.

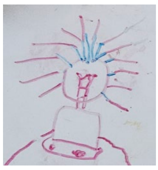
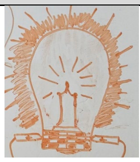
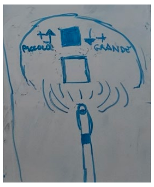
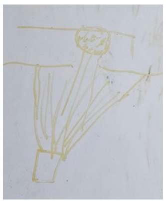
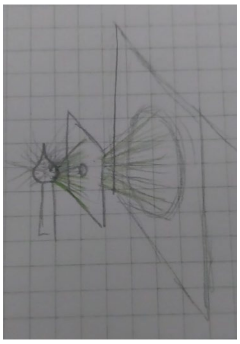
In this contribution, we will present results from trace analysis, which involves examining drawings as physical "tracks" left behind to trace the development history of an idea.

For classroom activities, our research was organized according to the Investigative Science Learning Environment (ISLE) framework, which provides an epistemologically authentic setting essential for executing a cognitive ethnographic inquiry (Etkina et al., 2019). ISLE is well suited for this research design because it mirrors the iterative process employed by scientists: children observe phenomena, identify patterns, construct explanatory models and hypotheses, and test these models through experimental predictions and revisions (Etkina, 2023). Within our cognitive ethnographic design, the ISLE process functions as a structured "cognitive trail." It allows us to observe how different experimental modalities—observational, testing, and application experiments—trigger specific epistemic shifts in the classroom. ISLE requires children to explicitly externalize their reasoning at each stage, it provides a rich stream of "mind-in-action" data. Drawings, in this context, become a central ontological disambiguator: it is the medium through which students bridge the gap between concrete observation to the abstract conceptualization in the experiential learning process tthey are in (Kolb, 1999). Ultimately, the ISLE framework ensures that the drawings we analyze are not mere visual reproductions, but generative semiotic artifacts produced during active scientific modeling. This alignment enables us to trace how students' internal mental models are restructured with the semantic goal through the social and material "orchestration" of the ISLE process.

3. Case study: Light sources and light propagation

We engaged four fifth-grade classrooms in our research program, involving a total of fifty-seven children. The ISLE activities extended for more than six hours per classroom. Table 1 summarizes the principal features of the developed ISLE process, children's drawings, and the trace analysis findings, with an emphasis on the conceptual change perspective.

Table 1. Epistemic process (from Ekina et al., 2019) and children's drawings.

Description of the ISLE process in action	**Epistemic role**	**Children's drawings**		**Conceptual change perspective**
Observational experiment A bulb is emitting light in all direction.	Observe and describe how light is emitted from the bulb, illuminating all the objects.	 One-ray model	 Multiple-ray model	**Externalization of intuitive ideas** To represent light, children need to build a model of ray. a ray is not a real thing; it is a model that allows us to show the direction of light.There are two possible mdels of how extended sources emit light: one-ray model (left) or multiple-ray model (right)
Testing experiment Place a powered, frosted lightbulb on a table in the center of a dark room. Take the point of a sharpened cube and place it close to the wall. Record what you observe. Next, move the cube toward the bulb and away from the wall.	Use the model to predict the outcome of the experiment.	 One-ray model	 Multiple-ray model	**Create disatisfaction towards intuitives' idea** Both models allow children to make the same prediction. This is not feasible. The experiment does not provide the opportunity to discriminate which model better represents light emission.
Testing experiment Cover the bulb with an aluminium foil and poke a hole in the foil in the mid facing the wall, or use a cardboard with a hole in the middle.in the middle Turn the bulb on.	Use the model to predict the outcome of the testing experiment.	 One-ray model	 Multiple-ray model	**Generating new, understandable knowledge** The testing experiments disprove the one-ray model and support the idea that each point on an extended light source emits light in many different directions. This light should be represented by multiple rays diverging from that point.
Application experiment Imagine that you put a candle (or bulb) on a table and place a piece of thin cardboard between the candle and a nearby wall. Use the figure to draw a ray diagram to predict what you will see on the wall if you make a tiny hole in the cardboard.	Apply concept for reasoning in different situation and explaining			**Plausability and usability of the new knowledge** Using multiple-ray model children are guided to reason about this new situation. Their prediction needs to be fixed more, but the transduction is operating in sense meaning from a conceptual standpoint, showing how the drawing act as semantic tool.

4. Discussion and conclusions

Our findings show how the Investigative Science Learning Environment (ISLE) framework acts as a 'cognitive trail,' reflecting scientific inquiry processes (Etkina et al., 2019; Etkina, 2023). By encouraging children to externalize reasoning through experiments, ISLE offers 'mind-in-action' data for observing cognitive shifts. Drawing became more than an activity; it became a proto-modeling tool needed for scientific reasoning (Yoon et al., 2021). In answering our first research question about the epistemic demands of correspondence and coherence, we saw children use drawing to navigate the tension between observation and understanding. Drawings often showed intellectual realism, depicting conceptually relevant features like light rays not visible, prioritizing internal coherence over visual realism. Regarding the second research question on conceptual change, drawing served as a powerful strategy for externalizing and restructuring implicit mental models (Vosniadou, 1994). Our trace analysis demonstrated a clear progression: initial drawings often reflected an intuitive "one-ray model" for light emission. Through ISLE testing experiments, which were designed to create dissatisfaction with these intuitive ideas, children were guided to reorganize their models toward a more scientifically robust "multiple-ray model" (Etkina et al., 2019). This transition highlights drawing as a conceptual facilitator, providing tangible, concrete reference points that facilitate deeper exploration of children's conceptions (Ehrlén, 2009). Central to this process is the dual role of drawing as both a **c**onceptual facilitator and a mediator in ontological disambiguation. As a facilitator, drawing enables children to manage complex information and move beyond "physical babbling" toward structured explanatory systems. As a mediator, drawing supports the transduction process, bridging the gap between concrete, lived experience and abstract scientific conceptualization (Kress, 2010; Ainsworth et al., 2011). By rendering internal models visible, drawing allows children to disambiguate their ontological commitments, making their ideas available for social negotiation and collective reflection (Kolb, 1999; Prain & Tytler, 2012). In conclusion, while drawing is a potent tool for science education, its effectiveness depends on intentional multimodal orchestration. When properly scaffolded within an inquiry-based framework like ISLE, drawing becomes an essential semantic tool that sustains reasoning through and from representation, ultimately leading to the construction of robust scientific knowledge.

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