Building bridges towards scientific thinking: potential dimensions to enrich research on precursor models

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ABSTRACT
Science education faces the persistent challenge of inert knowledge, where students fail to mobilize what they have learned to interpret phenomena. Within this framework, the notion of the precursor model emerges as a didactic tool to manage the "unassimilability gap" between students' initial representations and school science models. This theoretical reflection article examines the productive tension between the psychodidactic and epistemodidactic perspectives, proposing an articulation that incorporates the social dimension of learning from the perspective of distributed cognition. It also suggests that teachers' management of these models can function as an analytical lens to make visible the configurations of teacher professional knowledge. Drawing on a case study with primary school teachers, it shows how these configurations enable different approaches to the model, shifting the unit of analysis towards the socio-cognitive dynamic and linking the precursor model with scientific literacy as a social practice. Finally, it outlines challenges for a research agenda that positions precursor models as a cross-cutting axis for teacher professional development and a transformative science education.

KEYWORDS
Precursor models, physical sciences, scientific thinking, psychodidactic and epistemodidactic perspectives

RÉSUMÉ
La didactique des sciences fait face au défi persistant de la connaissance inerte, où les élèves ne parviennent pas à mobiliser ce qu'ils ont appris pour interpréter les phénomènes. Dans ce cadre, la notion de modèle précurseur émerge comme un outil didactique pour gérer « l'écart d'inassimilabilité » entre les représentations initiales des élèves et les modèles scientifiques scolaires. Cet article de réflexion théorique examine la tension productive entre les perspectives psychodidactique et épistémodadique, proposant une articulation qui intègre la dimension sociale de l'apprentissage du point de vue de la cognition distribuée. Elle suggère également que la gestion de ces modèles par les enseignants peut fonctionner comme une lentille analytique pour rendre visibles les configurations des connaissances professionnelles des enseignants. S'appuyant sur une étude de cas menée par des enseignants du primaire, il montre comment ces configurations permettent différentes approches du modèle, déplaçant l'unité d'analyse vers la dynamique sociocognitive et reliant le modèle précurseur à la culture scientifique en tant que pratique sociale. Enfin, il expose les défis d'un programme de recherche qui positionne les modèles précurseurs comme un axe transversal pour le développement professionnel des enseignants et une éducation scientifique transformatrice.

MOTS- CLÉS
Modèles précurseurs, sciences physiques, pensée scientifique, perspectives psychodidactiques et épistemodidactiques

INTRODUCTION

Science education faces a persistent problem that cuts across all educational levels: students learn scientific content but fail to use it to interpret phenomena, make informed decisions, or understand everyday situations. This phenomenon, characterized in the literature as inert knowledge (Perkins, 1992), reveals a significant gap between school learning and the functional appropriation of scientific knowledge. In previous work by our team on university-level teaching of the cardiovascular system (Arrese et al., 2020; Olivares et al., 2021), we have observed that this fragmentation of knowledge constitutes a recurrent obstacle, even when students are able to reproduce definitions accurately. From this perspective, the challenge lies not only in what content is taught, but in how the forms of thinking that students develop from it are configured and, fundamentally, to what extent these configurations prove transferable to new contexts.

Within this framework, the notion of the precursor model emerges as a particularly fruitful theoretical and didactic tool for thinking about the transition between students' initial representations and school science models. Initially developed in the field of mechanics for secondary school students (Lemeignan & Weil-Barais, 1993) and later extended to early childhood (Boilevin et al., 2022), this line of research does not propose a mere simplification of knowledge, but rather the deliberate construction of intermediate entities that act as conceptual molds (Ravanis, 2024). Its power lies precisely in its capacity to enable forms of reasoning that, without this mediation, would remain beyond the cognitive reach of the subject, managing what has been termed the "unassimilability gap" (Boilevin et al., 2022). We consider that the value of these models is not limited to their function as a cognitive bridge, but extends to their potential to make visible the very process of knowledge construction, an aspect we have explored in studies on modeling in university contexts (Olivares & Olivares, 2023).

However, the development of this line has given rise to internal debates and divergent emphases that present an opportunity to enrich the discussion. On the one hand, a psychodidactic perspective emphasizes the precursor model as a tool for cognitive scaffolding sensitive to student development (Ravanis, 2020). On the other hand, an epistemodidactic perspective insists on its status as a school theoretical model, with rules and functions proper to scientific knowledge (Adúriz-Bravo, 2022). This tension, far from constituting an obstacle, can be read as an opportunity to enrich the conceptualization of the field. In relation to previous research by our team on the articulation between cognitive and metacognitive dimensions in scientific education (Olivares et al., 2023), this discussion acquires particular relevance in questioning not only what models students construct, but also how they become aware of this construction and what didactic conditions favor it.

The aim of this article is to carry out a theoretical-conceptual analysis that, starting from a synthesis of the core of the proposal, (1) critically examines the tension between the psychodidactic and epistemodidactic perspectives, (2) proposes an articulation that incorporates the social dimension of learning, and (3) suggests a research agenda to consolidate the field, identifying pending empirical and formative challenges. The central argument holds that precursor models, understood as mediating cultural artifacts, can become fundamental springboards for a science education that prioritizes functional understanding and citizenship education.

In continuity with previous studies by our team on modeling at different educational levels (Arrese et al., 2020; Olivares et al., 2021), which have highlighted the importance of metacognition and the socio-cognitive nature of learning situations, this work seeks to contribute to a situated reflection on the conditions that make it possible for the models taught to become tools of genuine thought—that is, tools that students can consciously regulate and put into play in contexts of interaction and collective negotiation—and not new repositories of inert knowledge.

THE PRECURSOR MODEL AND THE MANAGEMENT OF THE UNASSIMILABILITY GAP: PROFESSIONAL IMPLICATIONS

The precursor model constitutes a functional thinking entity specifically designed to manage the gap between the student's knowledge and the rigor of school science. According to Ravanis (2024), these models are not simplified versions of expert knowledge, but intermediate didactic constructions that enable the subject to perform three essential functions: describing, explaining and predicting the evolution of phenomena. Boilevin et al. (2022) emphasize that the success of this mediation lies in providing the student with an operational 'mold' that has a reduced but calculable field of validity. Now, inhabiting this cognitive distance necessarily implies an active process of modeling that avoids the mere repetition of labels, an aspect we have explored in previous studies on the construction of scientific explanations in university contexts (Arrese et al., 2020; Olivares et al., 2021).

In relation to the nature of what is 'early', it is necessary to recognize that the independence between the precursor character and biological age constitutes a pillar already established in the foundational literature of the field. Weil-Barais (2022) and Lemeignan and Weil-Barais (1993) have shown that these models are relevant both in childhood and in secondary education, where consideration of the epistemological rupture with natural thinking becomes necessary. Recent research in early childhood education has shown that children are capable of constructing precursor models even for abstract concepts such as air, provided that activities are designed from inquiry approaches that promote prediction, observation and explanation (Sesto Varela et al., 2022). This finding reinforces the idea that 'precursor' does not refer to an age limitation, but to the conceptual distance that the model helps to bridge. However, what has been least explored so far is how the teacher uses precisely this distance as a strategic input to design their didactic intervention. The perspective we propose and put forward as a new thesis conception is that science teachers' professional knowledge offers a complementary view, shifting the focus from the student's cognitive machinery towards the deliberate intention of the teaching professional. This concern for the teacher's role in managing models dialogues with previous research by our team on science teacher education and their participation in interdisciplinary proposals (Olivares et al., 2023). Thus, the relevance of the precursor model lies in its validity to bridge unassimilability gaps at any educational level, but also in its power to make visible the didactic decisions that make this mediation possible.

In the master's thesis, a case study with two primary school science teachers in La Pampa, Argentina, the analysis of teaching practices allowed us to identify differences in how each teacher approached the modeling of physical phenomena (Arrese, 2024). While Sofía (a teacher with eleven years of experience but her first year teaching science) tended to limit work with phenomena to manipulation and technical description, Elena (a teacher with eight years of experience in the area and postgraduate training in science education) promoted activities that involved explanation and the formulation of complex predictions. This difference in the use of the functions proper to precursor models -description, explanation and prediction- proved suggestive: could it be that the way teachers approach modeling is related to the characteristics of their professional knowledge? The specialized literature has shown that teachers' professional knowledge, and in particular pedagogical content knowledge, influences the teaching of modeling (Justi & Gilbert, 2003; Justi, 2009). However, the way in which precursor models, as mediators of learning with specific functions, could operate as a lens to make visible this knowledge in action has not been explored in depth.

From this perspective, the differences observed between the two teachers allow us to understand that their respective configurations of Teacher Professional Knowledge (TPK) give rise to different ways of approaching the precursor model: prescriptive in Sofía, mediating in Elena. These configurations make visible aspects of the management of uncertainty and didactic transposition that would otherwise remain implicit. Now, this possible diagnostic function acquires special relevance when linked to metacognitive processes of reflection on practice, as we have pointed out in studies on self-regulated learning in science (Olivares & Olivares, 2023). For her part, while for Sofía the model operates as a prescriptive recipe, for Elena it becomes an instrument of mediation that activates relevant learning.

The originality of this view lies in conceiving the precursor model as a possible indicator of pedagogical sophistication, where the stability of the thinking entity could reflect the quality of mediation. This conception finds echoes in research carried out in other scientific domains. Ergazaki (2022), in studying the introduction of precursor models of genetic inheritance and natural selection in young children, shows how these models can operate as “molds for future cognitive constructions” that would otherwise be inaccessible. The author highlights that the articulation of precursor models in biology requires not only adapting scientific content, but also designing didactic sequences that consider both children's prior ideas and the epistemological obstacles to be overcome. In continuity with previous studies by our team on formative assessment and modeling (Olivares et al., 2023), this reflection provides tools for thinking not only about which models to teach, but also about how to train teachers capable of inhabiting them critically. The precursor model thus presents itself as a possible transversal axis that could contribute to teachers' professional development and, at the same time, lay the foundations for a citizen-oriented, functional and authentically transformative science education.

A PRODUCTIVE TENSION: HOW TO BALANCE COGNITIVE DEVELOPMENT AND EPISTEMOLOGICAL RIGOR IN PRECURSOR MODELS?

The debate between considering the precursor model as a mental entity or a cultural artifact finds a fruitful resolution in the notion of distributed cognition. Perkins (2018) proposes that learning occurs in a ‘Person Plus’ system, where intelligence does not reside exclusively in the head, but is distributed between the subject and their symbolic tools. In this light, the precursor model materializes in the inscriptions and gestures that circulate in the classroom; for example, the drawings of the "shape of sound" recently documented in a thesis (Arrese, 2024) are not external supports, but a constitutive part of the thinking entity (Pantidos et al., 2022).

This understanding is enriched by the distinction between the real, material and abstract planes of the model (Bermudez & Krell, 2025; Chamizo, 2010; Gilbert, 2004). The real plane refers to the phenomena of the world that are intended to be modeled—in this case, the propagation of sound; the material plane corresponds to the concrete representations that make it visible and manipulable (drawings, tokens, etc.); and the abstract plane alludes to the ideas, theories and conceptual relationships that give meaning to these representations. In Elena's case, the children's drawings were not mere reflections of what was observed, but operated as a material plane that, in interaction with the abstract plane (the idea that sound has a ‘shape’ that can be represented), allowed the model to be collectively explored and reformulated.

Now, this articulation of planes dialogues with previous studies by our team on the importance of making thinking processes visible in educational contexts (Olivares & Olivares, 2023). While psychodidactics seeks internal structures, the perspective of distributed cognition suggests that the model is the very collective negotiation of meanings mediated by material supports, which successively update the different planes. Thus, the precursor model constitutes a socio-cognitive phenomenon where the material supports of thought act as scaffolds for visible and shared thinking, allowing the construction of knowledge to transcend the individual limits of the student and move fluidly between experience, representation and theory.

This conception of the precursor model as a mediating cultural artifact does not ignore the difficulties faced by students and teachers in sustaining genuine modeling processes. Research in other scientific domains has shown that prediction and model modification activities tend to be the least frequent in classrooms, even when specially designed sequences are implemented to promote them (Bermudez & Krell, 2025; Khan, 2011; Krell et al., 2019). Nevertheless, there are experiences that manage to overcome these difficulties through carefully designed socio-cognitive interventions. In the study by Delserieys et al., (2022) on shadow formation, the authors show that a sequence of activities based on overcoming specific obstacles—such as the relationship between light source, opaque object and projection screen—allows 5-6-year-old children to construct explanations compatible with a precursor model of the phenomenon. This type of evidence suggests that the “unassimilability gap” can be didactically managed when the obstacles to be overcome are clearly identified and interventions are designed to address them systematically. However, the success of these interventions depends on the TPK of the teacher who implements them. This finding invites us to ask whether the “unassimilability gap” that precursor models seek to manage in students does not also operate at the level of teaching practice: how can we train teachers capable not only of teaching with models, but of inhabiting themselves the complete cycle of generation, evaluation and modification?

THE SOCIAL DIMENSION AND THE LINK WITH SCIENTIFIC LITERACY

The line of research on precursor models has incorporated the social dimension from its foundations through a socio-cognitive approach. Ravanis and Boilevin (2022) argue that these entities are constructed in interactions designed to destabilize initial representations and address epistemological obstacles. Likewise, Pantidos et al. (2022) emphasize the role of narrative and multimodality in the collective circulation of knowledge. However, in many developments, interaction appears mainly as a condition of possibility for individual conceptual change. In this framework, the social operates as a facilitator of internal processes rather than as a constitutive dimension of the model itself. A counterpoint to this reading is offered by Canedo Ibarra and Gómez Galindo (2022), who, in analyzing the construction of a precursor model of floating in early childhood education, show how social interaction is not limited to creating conditions for individual learning, but constitutes the very fabric of the model. In their study, the conceptual, procedural and affective-motivational conversations between teacher and children, and among peers, operate as spaces where the model is negotiated, stabilized and transformed. From this perspective, the social is not an addition, but the very medium in which the precursor model acquires meaning.

I propose to review this reading in light of distributed cognition (Perkins, 2018), where learning is conceived as a "Person Plus" system in which thought and symbolic tools intertwine. From this perspective, the precursor model is not limited to residing in mental structures, but materializes in inscriptions, discussions and shared regulations. Thus, the precursor character of the model refers not only to its transitional function with respect to scientific knowledge, but also to its emergence in collective practices of interpretation (Ravanis, 2024). This displaces the unit of analysis: it is no longer solely about the student's mind, but about the dynamics of the collective negotiation of meanings in the classroom where the precursor model becomes a shared entity.

This vision of the precursor model as a tool for managing epistemological ruptures at different educational levels aligns with broader approaches to modeling in science education. Oliva (2019) has pointed out that the idea of modeling admits various meanings—as epistemic practice, as didactic strategy, or as cognitive process—whose clarification is necessary for designing coherent teaching proposals. In this framework, the precursor model can be understood as a concretization of what Oliva (2024) calls "model weavers": didactic resources (analogies, models, personifications, inscriptions) that facilitate the progressive construction of scientific meanings. From this perspective, the drawings of the "shape of sound" documented in the thesis (Arrese, 2024) are not mere expressive supports, but authentic weavers that make students' thinking visible and negotiable. Moreover, Elena's case allows us to observe this dimension more clearly. During the sequence on sound, the inquiry into its possible "shape" was sustained through collective drawings, gestures and debates around the available evidence (Arrese, 2024). In this process, representations did not function as simple external supports, but as supports for conceptual coordination. As Pantidos et al. (2022) point out, this transition from realistic forms towards more abstract representations occurs in interaction with others and with available resources. In this sense, the precursor model does not precede interaction, but is configured within it and allows linking the precursor model with scientific literacy understood as social practice. Furman (2021) argues that learning science involves using knowledge to interpret new and significant situations, while Perkins (2018) warns of the risk of fragile knowledge that cannot be mobilized. Under this view, the relevance of the model does not depend exclusively on its conceptual adequacy, but on its potential to be used collectively in understanding phenomena. This idea resonates with research investigating how children construct explanations about complex phenomena such as clouds and rain. Georgantopoulou et al., (2022) show that when children participate in inquiry activities on these phenomena, their explanations combine descriptive elements with attempts to establish causal relationships between entities. In this process, language and graphic representation operate as tools that make thinking visible and allow its collective negotiation. Perhaps the question is not only whether the model approximates expert knowledge, but whether it enables forms of epistemic participation that transcend immediate school activity. Making this possibility explicit may authorize giving freedom, autonomy and new experiential learning (Camilloni, 2015).

CONCLUSION

The journey proposed throughout this article allows us to place the socio-cognitive dimension at the center of reflection on precursor models. Far from conceiving interaction as mere context or facilitator of individual conceptual change, arguments have been made that the precursor model is constituted in the collective negotiation of meanings. The drawings, the gestures, the discussions around evidence are not external supports to a process that occurs "in the head" of each student; they are the very fabric in which the model is stabilized, transformed and acquires meaning. This reading, anchored in frameworks such as distributed cognition (Perkins, 2018) and supported by studies showing how children construct explanations in interaction with others and with available resources (Canedo Ibarra & Gómez Galindo, 2022; Pantidos et al., 2022), displaces the unit of analysis towards the collective dynamic where the precursor model becomes a shared entity.

The tension between the psychodidactic and epistemodidactic perspectives, far from constituting a dichotomy to be resolved, can be read as a productive space for thinking about TPK. The experiences analyzed around the "shape of sound" (Arrese, 2024) suggest that the use the teacher makes of the model could evidence a professional sensitivity to recognize and enhance ongoing modeling processes. This view positions the precursor model not only as a tool for student learning, but as a possible analytical lens for understanding pedagogical sophistication and the development of TPK.

This displacement opens some directions of inquiry that could enrich the research line. Firstly, it would be valuable to deepen how the use and management of precursor models in the classroom make visible and enhance the teacher's abilities to mediate the epistemological rupture and manage uncertainty. This would imply developing instruments that allow teachers to reflect on their own modeling practices, training themselves as epistemological mediators capable of inhabiting error and uncertainty as opportunities for the refinement of thinking. Secondly, one might ask under what didactic conditions these constructions manage to sustain mobilizable learning. The lack of studies on the longitudinal stability of precursor models, pointed out by Georgantopoulou et al., (2022), opens some questions: is permanence over time the only criterion for evaluating the solidity of a precursor model? Or does its power also reside in its capacity to be mobilized in contexts different from the classroom, in situations that demand interpretation, decision or action? From the perspective developed here, the validity of a model is not validated solely in its fixation in individual memory, but in its potential to enable forms of epistemic participation that transcend immediate school activity. This view does not ignore the value of investigating the continuity of models over time, but invites us to ask whether this continuity should be thought of as a stable replica of an entity or as a flexible repertoire for interpreting new situations. In this sense, the social functionality of the model (its capacity to avoid inert knowledge) could constitute a criterion of validation as relevant as its cognitive persistence. The question, then, would not be to choose between one direction or the other, but to explore how both dimensions are articulated.

Thirdly, it would be pertinent to design observation and analysis systems sensitive to distributed cognition in the classroom. Adapting existing tools would allow us to investigate what type of interventions (explanations, retrieval of prior knowledge, requests for visualization, predictive questions, among others) favor the emergence, stabilization and enrichment of collectively constructed models. Far from ignoring the rich tradition of studies on precursor models at different educational levels, the aim is to complement that tradition with analytical tools that allow us to analyze and compare what occurs in didactic interaction.

These challenges, of a theoretical, formative and methodological order, configure a research agenda that articulates rigor with the social utility of school science. By integrating the social dimension of knowledge, TPK and distributed cognition, precursor models present themselves as a possible transversal axis for teacher professional development and, at the same time, as a starting point for a citizen-oriented, functional and transformative science education.

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