

Rethinking Precursor Models in Science Education: reflections on an evolving field

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ABSTRACT

Within constructivist theory which has dominated science education over recent decades, precursor models have emerged as a distinct area of inquiry. First introduced by Lemeignan and Weil-Barais in secondary education and later extended to Early Childhood Education by Ravanis and Boilevin, the concept has developed along a noteworthy trajectory across educational levels. Building on foundational work in the field, this special issue of the Mediterranean Journal of Education brings together contributions from a second generation of researchers who continue to elaborate and refine this line of research. Drawing on the contributions included in this issue, the present paper aspires to reflect on the evolving study of precursor models and to contribute further to the ongoing discussion.

KEYWORDS

Precursor models, Science Education, reflections on evolving research

RÉSUMÉ

Dans le cadre du constructivisme, qui a dominé la recherche en didactique des sciences au cours des dernières décennies, les modèles précurseurs sont apparus comme un domaine distinct de recherche. Introduits pour la première fois par Lemeignan et Weil-Barais dans l'enseignement secondaire, puis étendu à l'éducation de la petite enfance par Ravanis et Boilevin, ce concept a connu une trajectoire remarquable à travers les différents niveaux d'enseignement. S'appuyant sur les travaux fondateurs dans ce domaine, ce numéro spécial du Mediterranean Journal of Education réunit des contributions d'une deuxième génération de chercheurs qui poursuivent l'élaboration et l'affinement de ce champ de recherche. À partir des contributions réunies dans ce numéro, le présent article se propose de réfléchir à l'évolution de l'étude des modèles précurseurs et de contribuer à la discussion en cours.

MOTS- CLÉS

Modèles précurseurs, didactique des sciences, réflexions sur l'évolution de la recherche

INTRODUCTION

Drawing from post-Piagetian theories on learning as well as Vygotsky's analysis of the development of scientific concepts, constructivism has dominated the field of Science Education in recent decades and has exerted a major influence on the teaching and learning of school science (Driver et al., 1985; Ravanis, 2021). At the core of this theory lie alternative

ideas, which are mental representations that pupils form in their minds in their attempt to understand and conceptualize the natural phenomena around them. These ideas have a solid basis, as they derive both from children's everyday interaction with the natural world as well as from social life and language use, and, quite importantly, differ from scientifically accepted views (Alwan, 2011; Driver et al., 1994). Therefore, alternative ideas play a fundamental role within constructivist theory, as they constitute the starting point of teaching, which aims to achieve conceptual change so that these ideas become compatible with school science. Consequently, a number of researchers have extensively tried to explore and record alternatives ideas of students regarding different physics concepts such as energy, mechanics, heat, electricity and optics (Delsérieys et al., 2017; Mercier-Dequidt & Morge, 2014; Pantidos & Givry, 2021; Ravanis et al., 2002; Sissamperi & Koliopoulos, 2021).

While constructivism clearly describes both the role of the teacher, who functions supportively within the Zone of Proximal Development, and the role of the student, who is placed at the center of the learning process (Driver et al., 1985; Ravanis, 2021), the theory avoids describing precisely the stages of the path through which alternative ideas about a phenomenon become compatible with scientifically accepted views. That is, it does not identify distinct stages through which alternative ideas pass during their transformation into scientifically accepted ideas. Within this context, Lemeignan and Weil-Barais (1993) proposed the term precursor models which are cognitive entities that function as intermediate forms between children's initial ideas and the scientific models employed in education, while also enabling pupils to develop ways of thinking that overcome the limitations of their existing ideas and become aligned with scientific reasoning (Ravanis, 2021). Speaking in terms of physics and particularly semiconductors, precursor models are like the process of electron excitation and the subsequent creation and motion of holes in the valence band, which underlies charge carrier dynamics between the valence and conduction bands. Just as hole states provide an effective framework for describing carrier transport in semiconductors, precursor models function as intermediate cognitive structures that support the transformation of pupils' initial ideas into scientifically accepted ones.

The term precursor model was first introduced in the context of secondary education, particularly in relation to the way adolescents aged 16-18 construct basic concepts of mechanics such as force, energy, and momentum. As it was considered a promising and useful tool for bridging the gap between alternative and scientifically accepted ideas, the term was introduced into Early Childhood Education at the beginning of the 21st century (Ravanis, 2000, 2005). Despite the particularities that characterize science teaching in early childhood, this idea proved fruitful and eventually developed into a distinct approach within the socio-cognitive framework of Early Childhood Science Education (Ravanis, 2021). Almost twenty years after the first introduction of the term, a considerable number of researchers in the field of Early Childhood Science Education have explored the construction of precursor models across a variety of natural phenomena such as floating and sinking, shadows formation, water change states, air, clouds and rain, electricity, genetic inheritance and natural selection (Boilevin et al., 2022).

Almost 30 years after the first appearance of the term precursor models in Science Education and 25 years after its incorporation into Early Childhood Science Education, a new generation of researchers appear to be engaging with the concept. Following the pioneering work of earlier scholars in the field, they seem willing to further deepen both the theoretical and practical use of the term by raising new questions and shedding light on aspects that may play either a minor or a major role in the further exploration of the issue. Within this context, the current special issue of Mediterranean Journal of Education hosts contributions from this second generation of researchers working on precursor models, while the present article aspires to offer some deeper reflections to the discussion.

REFLECTIONS ON THE EVOLVING STUDY OF PRECURSOR MODELS

As precursor model research gradually moves beyond its pioneering phase, a number of new questions and perspectives emerge. The papers included in this special issue offer an opportunity to reflect on these issues and explore their broader implications within the field. The following sections focus on some of these themes, which appear particularly important for further exploring the nature, construction, and educational use of precursor models.

Toward more elaborated constructions of Precursor Models

Moving beyond the pioneering phase of research on precursor models, it would be useful to further develop more detailed descriptions of precursor models for each key concept in the natural sciences, as well as to examine the types of materials that are appropriate and may play an important role in the construction of precursor models for each of these concepts. In line with this perspective, García-Rodeja Gayoso et al. (2026) highlights the crucial role of materials and objects in the construction of such models, as they enable children to make inductive generalizations aligned with the intended precursor model. In particular, the authors conducted a literature review on the construction of precursor models related to floating and the buoyancy of objects. Their findings suggest that the use of solid objects in the process of model construction significantly helps children take the first step toward a model based on the density of both the material of the object and the fluid in which it floats. Interestingly, Kermen (2026) notes that most studies on precursor models have been based on materials, objects, experiments, and children's direct interaction with phenomena. This observation further highlights the important role that materiality may play in the construction of precursor models.

Incorporating precursor models into more specialized teaching approaches may further support children in progressing toward models compatible with scientific knowledge, while also contributing to the development of important 21st-century scientific skills such as creativity, critical thinking, communication, and collaboration. Ioannou (2026) refers to the Engineering Design Process (EDP) as a particularly relevant example of such an approach. The EDP consists of four distinct stages namely problem identification, inquiry, designing and testing, and conclusions and presentations which children follow through a structured and visualized process. As Ioannou (2026) states, the EDP can strongly support the development of a precursor model for the water cycle in preschool children through the gradual construction of four precursor models related to water state changes: vaporization, condensation, precipitation, and melting. From this perspective, the Engineering Design Process appears particularly suitable for supporting the construction of precursor models by creating opportunities for children to mobilize their prior ideas, engage in inquiry, and participate in experimentation. Through this process, children can progressively be guided toward the development of scientific thinking and scientific skills.

A similar perspective is proposed by de Echave Sanz and Serón Torrecilla (2026), who examine the role of precursor models within the framework of Design-Based Research and experiential learning. Drawing on a series of interventions involving phenomena such as buoyancy, electricity, light, sound, and combustion, they argue that precursor models can be effectively supported through the Predict–Observe–Explain (POE) strategy. According to the authors, POE creates opportunities for learners to activate their prior ideas, confront them with observations, and progressively reorganize their thinking. Quite importantly, the authors suggest that this process can support not only children's learning but also the appropriation of precursor models by pre-service teachers, contributing simultaneously to the development of scientific reasoning and pedagogical content knowledge. This appropriation becomes particularly evident in more complex experimental setups, such as those involving a Van de Graaff electrostatic generator, where the device's autonomous charge accumulation makes it

easier to analyze teachers' underlying conceptual models. In this sense, precursor models function as important mediating structures that connect learners' initial representations with more sophisticated forms of scientific reasoning.

Stability, transferability and multiplicity of Precursor Models

Moreover, a particularly critical dimension of precursor models that deserves further attention concerns their stability and transferability. Kambouri (2026) highlights this issue by pointing out that it remains unclear whether precursor models persist over time or can be transferred across different domains. Indeed, it is particularly interesting to consider whether a student who has constructed a precursor model in a specific cognitive domain, such as electricity, may be able to draw upon this construction in order to develop, with appropriate guidance, another precursor model in a different scientific domain. Such a possibility raises questions about whether precursor models function only as context-dependent cognitive constructions or whether they may also support broader ways of reasoning and approaching scientific phenomena. Of course, as mentioned above, the temporal stability of these models is also an important issue. Longitudinal research is needed to explore the extent to which precursor models remain active in students' thinking after they have been constructed (Kambouri, 2026).

In addition, an interesting issue concerns the extent to which only one precursor model mediates between students' initial ideas and scientifically accepted views, or whether more than one precursor model may emerge during this process. In such a case, it would be particularly interesting to explore whether the construction of an initial precursor model facilitates the development of a second one, progressively leading students toward the acquisition of the scientifically accepted idea. From this perspective, the transition from students' initial ideas to scientific knowledge may involve a sequence of intermediate cognitive constructions rather than a single conceptual reorganization. This possibility raises questions regarding the potential relationships, continuities, and transformations between different precursor models that may appear throughout the learning process.

A further point of reflection concerns the possibility that, within the same category of phenomena, different alternative ideas may make certain precursor models more appropriate than others. In this sense, different precursor models could potentially function as different instructional targets in the course of students' conceptual change, depending on the particular alternative ideas they initially hold. Such a perspective suggests that children may not necessarily pass through the same precursor model on their way toward scientifically accepted knowledge when they are dealing with the same phenomenon. Instead, the selection or construction of a precursor model may depend on the specific characteristics and organization of students' initial conceptions.

Teacher mediation in the construction of Precursor Models

Another issue that arises as the precursor model research evolves concerns the extent to which science teachers are capable of incorporating these models into their teaching practices, as well as the ways in which they actually do so. Kambouri (2026) refers to this, pointing out that even if the significance of children's ideas is recognized at a theoretical level, teachers often lack the pedagogical tools to incorporate them into their teaching practice. Kermen (2026) approaches this issue from a slightly different perspective by arguing that precursor models may serve different functions for different actors involved in science education. While for children they may function as tools for describing and explaining phenomena, for teachers they may serve as teaching goals as well as tools for organizing classroom activities. From this perspective, the effective use of precursor models requires not only knowledge of the models themselves but also an understanding of students' difficulties, constructivist principles, and appropriate teaching strategies. Blat (2026) contributes to this discussion by arguing that precursor models

should not be viewed solely as didactical tools for students, but also as instruments that shape and organize teachers' professional activity in the classroom. Drawing on the notion of 'intentional dynamics', she suggests that precursor models may support teachers in anticipating students' responses, identifying potential learning difficulties, and regulating classroom interactions during science teaching. In this sense, the use of precursor models appears to be closely connected not only to students' conceptual activity, but also to the ways teachers interpret, organize, and mediate the teaching process itself.

Arrese (2026) also shed light into this issue by suggesting that precursor models may be approached in practice in two different ways: as prescriptive or as mediating tools. As she points out, Teacher Professional Knowledge (TPK) is likely to play a key role in this process. More specifically, she refers to two cases of teachers: Sofia, who, although experienced as a teacher, is working as a science teacher for the first time, and Elena, who has extensive experience as a science teacher as well as postgraduate training in this field. Arrese notes that, while for Sofia the model operates as a prescriptive recipe, for Elena it becomes an instrument of mediation that activates relevant processes. That is, while in Sofia's case the precursor model appears to function mainly as a structured teaching guide that organizes classroom activity according to predetermined steps, Elena seems to employ the model more flexibly, using it as a means to interpret students' thinking and support the progressive transformation of pupils' ideas through interaction and dialogue.

Extending this line of thought further, both Arrese (2026) and Blat (2026) raise the question of whether the way teachers approach modeling may provide insight into their TPK. This perspective suggests that precursor models may function not only as tools for supporting pupils' conceptual development, but also as indicators of how teachers understand science teaching and learning. In this sense, the use of precursor models could reveal teachers' ability to recognize students' alternative ideas, support conceptual change processes, and adapt their teaching practices according to classroom interactions. Therefore, studying the ways teachers use precursor models may also help researchers better understand teachers' pedagogical thinking and didactical orientations.

Along similar lines, Oke Nguyen (2026) raises the question of whether precursor model research should focus not only on the models constructed by children but also on those employed by teachers during the planning and implementation of teaching. From this perspective, precursor models may be viewed not only as tools that support students' learning but also as resources that help teachers organize, interpret, and mediate classroom activity. Such an approach suggests that studying teachers' precursor models may provide valuable insights into their pedagogical thinking and professional knowledge, while at the same time broadening the scope of precursor model research beyond students' conceptual development.

The role of language and representation in Precursor Models

Another particularly important issue concerning the nature of precursor models relates to their social dimension. Since precursor models are situated within the framework of constructivism, it is both logical and expected that they possess a social dimension. Lev Vygotsky, one of the foundational figures of constructivism, emphasized the social dimension of learning and placed language at its center, considering it a fundamental tool for both social and cognitive development. Within this perspective, precursor models also constitute shared entities in the classroom, collectively negotiated and co-constructed by children within a social and linguistic context (Ravanis, 2024). Therefore, the role of language in the construction of precursor models becomes particularly interesting. Gomez-Galindo (2026) refers to this issue, pointing out that rather than incorporating scientific language at the beginning of the teaching process, it may be more productive for it to be integrated into modeling at a later stage. More specifically, conceptualizing language use as a continuum, with children's everyday, messy, and flexible

language at one end and scientific language at the other, she argues that the language employed in the construction of precursor models is situated within a Third Space that emerges in the science classroom and allows for the reframing of students' discourse. Particularly characteristic is the example she presents while working with children aged 4 to 6 years old on the precursor model of "irritability" in living beings, where children, through appropriate teacher guidance, gradually moved from the everyday expression 'little wires' to the more scientific term 'nerve fibres'.

Apart from language, Gomez-Galindo (2026) also points out that the construction of meaning in the science classroom is not limited to oral language. She further refers to the role of other representational forms such as drawings, graphs, inscriptions, and other semiotic resources produced within the classroom, which play an important role both in the construction of models and in the teaching and learning process more generally (Gomez-Galindo, 2009; Pantidos et al., 2022). Arrese (2026) also refers to this issue, highlighting the usefulness of giving models a tangible dimension in supporting their conceptualization by children. More specifically, she presents the example of the 'shape of sound' arguing that children's drawings and tokens may function as a material plane which, in interaction with the abstract idea that sound has a 'shape' that can be represented, can play a catalytic role in the construction of a precursor model for sound. Along this line, Kermen (2026) also points out that greater attention should be paid to the ways meanings are negotiated in classroom interactions during the construction of precursor models. From this perspective, understanding how children and teachers jointly construct and share meanings may be an important direction for future research.

Pantidos and Fotiadi (2026) introduce an additional dimension to precursor model research by exploring how embodiment may contribute to the construction of precursor models in science education. They focus on the concept of friction, noting that although it holds a central position in science curricula, it is often reduced in school science to a simple resistive force overlooking the more complex interfacial dynamics and its role in energy dissipation. The authors highlight the logical contradiction experienced by students since mass appears to play a crucial role in the generation of friction while simultaneously having no apparent effect on stopping distance. In order to address this contradiction, they propose a precursor model of friction grounded in an ontological analysis of the phenomenon. More specifically, the model is based on four main characteristics: the interface as an emergent product of interacting systems, the electromagnetic grounding of interfacial interactions, system reciprocity and process decomposition, and the reconfiguration of the variables used to predict stopping distance. From this perspective, the human body may function as a valuable resource for exploring interfacial relations, since bodily movement naturally incorporates features such as relative motion, coupling, resistance, release, and gradual sliding.

Precursor Models in Special Needs Education context

In recent years, there has been an effort within the field of Science Education to expand teaching and learning science and particularly constructivist theory into the field of Special Education (Brigham et al., 2011; Sofianidis & Stylianidou, 2025). In this context, the alternative ideas of students that lie within Special Education spectrum such as adolescents with high-functioning autism, preschool children with learning difficulties and secondary school students with hearing impairments have been studied in relation to various physics phenomena (Araujo Florentino et al., 2023; Kalampos et al., 2021, 2023; Katsidima et al., 2023). As these alternative conceptions among children in Special Education are gradually being mapped, a particularly interesting research direction is emerging regarding the possible construction of precursor models for these populations.

More specifically, it would be particularly interesting to examine the extent to which children in Special Education contexts are able to construct precursor models, as well as

whether these models are similar or different from those constructed by typically developing children. If the alternative ideas of children in Special Education differ from those of typically developing children regarding a specific scientific concept, it becomes reasonable to explore whether different precursor models may also be required in order to progressively lead these students toward scientifically accepted knowledge. At the same time, even in cases where shared alternative ideas are identified across the two populations for a particular scientific concept, it remains interesting to examine whether children should be guided toward the construction of similar or distinct precursor models in order to eventually acquire scientific knowledge. For example, Kaliaspos et al. (2023) found that high-functioning autistic adolescents rarely use the Push/Pull model in their attempts to identify forces acting on different bodies. This finding may have important implications for the construction of precursor models related to mechanics in these students. Of particular interest would also be the exploration of the role that precursor models may play in the teaching and learning processes of gifted children characterized by particularly advanced cognitive abilities. Consequently, extending precursor model research into the field of Special Education undoubtedly represents a particularly interesting challenge.

CONCLUSION

Nearly three decades after the introduction of the notion of precursor models into Science Education and twenty-five years after its incorporation into Early Childhood Science Education, the field appears to be entering a new phase of development. The contributions brought together in this special issue of the Mediterranean Journal of Education provide indications that research on precursor models is gradually moving beyond its initial exploratory phase toward a more mature phase of development.

In particular, the need for more elaborated descriptions of precursor models, as well as a deeper understanding of the conditions that support their construction, emerges as an important issue for the further development of the field. At the same time, questions concerning stability, transferability, and possible multiplicity of precursor models appear to be particularly relevant for understanding how conceptual development unfolds over time. Another significant dimension concerns the role of teachers and Teacher Professional Knowledge in supporting and mediating the construction and educational use of precursor models. The importance of language, representations, and multimodal forms of communication such as embodiment also emerges as a key aspect of the processes through which precursor models are negotiated and shared within the science classroom. Finally, the possibility of extending precursor model research into new educational contexts, including Special Education, appears to constitute a promising direction for broadening both theoretical and practical development of the field.

Taken together, these reflections suggest that precursor models should not be viewed merely as intermediate cognitive constructions between children's alternative ideas and scientific knowledge. Rather, they appear as complex entities shaped through the interaction of learners, teachers, language, materials, and social practices within the classroom. In this sense, precursor models constitute a particularly productive framework for understanding and supporting conceptual development in Science Education. At the same time, the issues discussed throughout this special issue reveal that many important questions remain open. Consequently, precursor models continue to represent not only a productive framework for interpreting conceptual development, but also a fertile field for future theoretical, empirical, and educational research in Science Education.

REFERENCES

- Alwan, A. (2011). Misconception of heat and temperature among physics students. *Social and Behavioral Sciences*, 12, 600-614.
- Araujo Florentino, C. P., Shimada, M. S., & Locatelli, S. W. (2023). Prior knowledge about science from drawings by a group of deaf students. In V. Lamanuskas (Ed.), *Science and technology education: New developments and Innovations. Proceedings of the 5th International Baltic Symposium on Science and Technology Education (BalticSTE2023)* (pp. 28-37). Scientia Socialis Press. <https://doi.org/10.33225/BalticSTE/2023.28>.
- Arrese, F. (2026). Building bridges towards scientific thinking: potential dimensions to enrich research on precursor models. *Mediterranean Journal of Education*, 6(2), 2-11. <https://doi.org/10.26220/mje.5619>.
- Blat, M. (2026). Le modèle précurseur comme instrument de l'activité : Une approche par les dynamiques intentionnelles. *Mediterranean Journal of Education*, 6(2), 24-29. <https://doi.org/10.26220/mje.5624>.
- Boilevin, J.-M., Delserieys, A., & Ravanis, K. (Eds.). (2022). *Precursor Models for teaching and learning Science during early childhood*. Springer. <https://doi.org/10.1007/978-3-031-08158-3>.
- Brigham, F. J., Scruggs, T. E., & Mstropieri, M. A. (2011). Science education and students with learning disabilities. *Learning Disabilities Research and Practice*, 26(4), 223-232.
- de Echave, A., & Seron, F. J. (2026). The use of precursor models in design-based research. *Mediterranean Journal of Education*, 6(2), 56-63. <https://doi.org/10.26220/mje.5629>.
- Delserieys, A., Impedovo, M.-A., Fragkiadaki, G., & Kampeza, M. (2017). Using drawings to explore preschool children's ideas about shadow formation. *Review of Science, Mathematics and ICT Education*, 11(1), 55-69.
- Driver, R., Guesne, E., & Tiberghien, A. (1985). *Children's Ideas in Science*. Milton Keynes: Open University Press.
- Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, 23(7), 5-12.
- García-Rodeja Gayoso, I., Sesto Varela, V., Lorenzo Flores, M., & Vázquez Martínez, S. (2026). Building precursor models of buoyancy: a review of current knowledge and future directions. *Mediterranean Journal of Education*, 6(2), 12-23. <https://doi.org/10.26220/mje.5623>.
- Gomez Galindo, A. A. (2009). Analysis of the use of drawings and scale models in the construction of multi-modal explanations by primary students when studying the sense of sight. In M. Hammann, A. J. Waarlo & K. Boersma (Eds), *The Nature of Research in Biological Education: Old and new perspectives on theoretical and methodological issues* (pp. 167-184). CD-β Press.
- Gomez-Galindo, A. (2026). Precursor models in early science education: a multimodal perspective. *Mediterranean Journal of Education*, 6(2), 39-48. <https://doi.org/10.26220/mje.5626>.
- Ioannou, M. (2026). Facilitating the construction of Precursor Models through Early STEAM Education. *Mediterranean Journal of Education*, 6(2), 30-38. <https://doi.org/10.26220/mje.5625>.

- Kaliampou, G., Ravanis, K., & Vavougiou, D. (2021). A comparison study of alternative conceptions on impetus theory and projectile motion of adolescents with typical development and high functioning autism spectrum disorder. *International Journal of Science Education*, 43(1), 128-156. <https://doi.org/10.1080/09500693.2020.1859156>.
- Kaliampou, G., Mavropoulou, S., Koliou, V., Ravanis, K., & Vavougiou, D. (2023). An experimental investigation of alternative ideas of force in autistic adolescents. *Research in Science Education*, 53(3), 867-888. <https://doi.org/10.1007/s11165-023-10115-8>.
- Kambouri, M. (2026). Rethinking precursor models in early childhood science education: reflections, tensions, and future direction. *Mediterranean Journal of Education*, 6(2), 49-55. <https://doi.org/10.26220/mje.5627>.
- Katsidima, M., Lavidou, K., Kornelaki, A., & Kaliampou, G. (2023). An investigation on alternative ideas on thermal phenomena of pupils with and without learning difficulties. *SN Social Sciences*, 3(1), 1-19. <https://doi.org/10.1007/s43545-022-00603-5>.
- Kermen, I. (2026). Diverses facettes du modèle précurseur : complexité et richesse. *Mediterranean Journal of Education*, 6(2), 64-74. <https://doi.org/10.26220/mje.5643>.
- Lemeignan, G., & Weil-Barais, A. (1993). *Construire des concepts en physique : L'enseignement de la mécanique*. Hachette.
- Mercier-Dequidt, C., & Morge, L. (2014). Analyse épistémologique et didactique d'une nouvelle analogie pour enseigner l'électrocinétique. *Canadian Journal of Science, Mathematics and Technology Education*, 14, 187-206. <https://doi.org/10.1080/14926156.2014.903318>.
- Oke Nguyen, N. A. (2026). Modèles précurseurs à l'apprentissage des Sciences Physiques et Naturelles. Questions ouvertes et perspectives. *Mediterranean Journal of Education*, 6(2), 85-92. <https://doi.org/10.26220/mje.5652>.
- Pantidou, P. & Fotiadi, S. (2026). Constructing a precursor model of friction through ontological analysis, learners' ideas, and modeling theory: towards an embodied inquiry framework. *Mediterranean Journal of Education*, 6(2), 75-84. <https://doi.org/10.26220/mje.5650>.
- Pantidou, P., & Givry, D. (2021). A semiotic approach for the teaching of energy: Linking mechanical work and heat with the world of objects and events. *Review of Science, Mathematics and ICT Education*, 15(2), 5-30. <https://doi.org/10.26220/rev.3563>.
- Pantidou, P., Fragkiadaki, G., Kaliampou, G., & Ravanis, K. (2022). Inscriptions in science teaching: From realism to abstraction. *Frontiers in Education*, 7, 905272. <https://doi.org/10.3389/educ.2022.905272>.
- Ravanis, K. (2000). La construction de la connaissance physique à l'âge préscolaire : Recherches sur les interventions et les interactions didactiques. *Aster*, 31, 71-94.
- Ravanis, K. (2005). Les sciences physiques à l'école maternelle: éléments théoriques d'un cadre sociocognitif pour la construction des connaissances et/ou le développement des activités didactiques. *International Review of Education*, 51(2/3), 201-218. <https://doi.org/10.1007/s11159-005-1885-x>.
- Ravanis, K. (2021). The Physical Sciences in Early Childhood Education: theoretical frameworks, strategies and activities. *Journal of Physics: Conference Series*, 1796, 012092. <https://doi.org/10.1088/1742-6596/1796/1/012092>.
- Ravanis, K. (2024). The Precursor Models in Natural Sciences learning and teaching. Paper presented at *Third Young Scholar Symposium on Science and Mathematics Education 2024*

(YSSSEE 2024). Universitas Islam Negeri Raden Intan Lampung, Indonesia. <https://doi.org/10.5281/zenodo.18742360>.

Ravanis, K. Papamichaël, Y. & Koulaidis, V. (2002). Social marking and conceptual change: the conception of light for ten-year old children. *Journal of Science Education*, 3(1), 15-18.

Sissamperi, N., & Koliopoulos, D. (2021). How students of primary school understand large scale energy systems: The case of thermal power plant. *Journal of Technology and Science Education*, 11(1), 129-145. <https://doi.org/10.3926/jotse.1137>.

Sofianidis, A. & Stylianidou, N. (2025). Towards an inclusive science education: preparing twenty-first century preschool student teachers for inclusive science teaching and learning, *International Journal of Science Education*, 1-26. <https://doi.org/10.1080/09500693.2025.2595578>.