Designing teaching activities based on the precursor model for electricity in early childhood education

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ABSTRACT

The aim of this study is to describe a context for developing teaching activities for electricity in early childhood education. It leverages the concept of the precursor model, which comprises mental representations exhibiting characteristics of naive knowledge while also incorporating elements compatible with scientific models. Data from three studies are utilized, demonstrating that the precursor model of preschool-aged children for electricity exhibits phenomenological features, where children: a) empirically approach electricity as an entity that causes specific effects, b) perceive it as something that can be transported, c) conceptualize the technical components of an electric circuit, and d) construct simple electric circuits. For this reason, a framework for developing instructional activities is proposed, emphasizing technology and children's actions on objects rather than the construction of pre-scientific mental models based on a microscopic level.

KEYWORDS

Early Childhood Science Education, precursor model, teaching activities, electricity

RÉSUMÉ

L'objectif de cette étude est de décrire un contexte pour développer des activités d'enseignement sur l'électricité dans l'éducation de la petite enfance. Elle s'appuie sur le concept du modèle précurseur, qui comprend des représentations mentales présentant des caractéristiques d'une connaissance naïve tout en incorporant également des éléments compatibles avec les modèles scientifiques. Les données de trois études sont utilisées, démontrant que le modèle précurseur des enfants d'âge préscolaire pour l'électricité présente des caractéristiques phénoménologiques. Dans ce cadre les enfants : a) abordent empiriquement l'électricité comme une entité qui provoque des effets spécifiques, b) la perçoivent comme quelque « chose » qui peut être transporté, c) conceptualisent les composants techniques d'un circuit électrique, et d) construisent des circuits électriques simples. Pour cette raison, un cadre pour développer des activités pédagogiques est proposé, mettant l'accent sur la technologie et les actions des enfants sur les objets plutôt que sur la construction de modèles mentaux préscientifiques basés sur un niveau microscopique.

MOTS-CLÉS
Éducation scientifique à la petite enfance, modèle précurseur, activités d'enseignement, électricité

INTRODUCTION

Research on learners' mental representations has epistemologically defined the field of science education. Students' mental representations are usually referred in the literature as intuitive knowledge, misconceptions, pre-existing conceptions or preconceptions, initial ideas, and alternative ideas, terms that imply different epistemological implications (Alwan, 2011). Intuitive knowledge can be understood as knowledge acquired through everyday experiences while misconceptions explicitly indicate conceptual conflicts with scientific models. On the other hand pre-existing conceptions or preconceptions emphasize that ideas exist prior to formal instruction and may differ from the scientifically accepted that will be taught, initial ideas refer to the initial state of learning in advance of any kind of instruction, while alternative ideas are perceived not as incorrect but as different perspectives or alternative views.

Fleer (1991) studied the difficulties faced by 3-5-year-olds children when dealing with electric current in early childhood education context. Her findings suggest that differences between everyday and scientific language, as well as limited experiences, contribute to their challenges. Noteworthy, she claims that teachers should play a vital role in guiding exploratory comprehension. Concerning electricity and electrical appliances Solomonidou and Kakana (2000) observed that children perceive electricity as static, stored inside appliances. They pointed out that, while children tend to associate the fact of purchasing an appliance with electricity, they fail to connect it to battery-powered toys or batteries themselves. In addition, Kalogiannakis and Lantzaki (2012) argue that some children view electrical appliances as non-electric objects. They also mention that the drawing of electrical circuit, wiring is quite challenging for children. Electrical circuits pose challenges for 5-6-year-olds, as highlighted by Glauert (2009). Childrens' understanding of connections and explanations varies greatly and there is often a mismatch between their predictions and actions within the context of electrical circuits.

In the traditional view we understand these mental representations as cognitive limitations and obstacles to learning process. Eventually, through appropriate teaching approaches, students are given the opportunity to destabilize their conceptions transforming them into models with elements compatible with those of natural sciences. Note that school science constitutes a transposed version (e.g., Bohr's atomic model) of a reference knowledge aiming to be accessible to learners at each grade level (Bergsten et al., 2010; Chevallard, 1985; Martinand, 1989). Reference knowledge can be considered the scientific knowledge produced by researchers in universities and research institutes, as well as the school knowledge of previous or higher educational levels. School knowledge, therefore, appears in textbooks, curricula, and the practices adopted by educators (Delegkos & Koliopoulos, 2020). Thus, the distinction between reference (scientific) knowledge and its transposed version (school) is primarily based on the latter's need to be suitable for learning, meaning it should be functional in modifying learners' alternative ideas (Kariotoglou et al., 1990; Zoupidis et al., 2021). Thus, in the context of didactic transposition, school knowledge may take on a conceptual rather than computational focus, encompassing specific concepts and phenomena or determining the sequence in which these concepts or modules will be taught (e.g., starting with Newton's third law and then the first and second laws). Additionally, consideration is given to the modalities used to present the knowledge (e.g., inscriptions, gestures) and decisions are also made regarding whether to include the steps of experimental teaching and so on.

However, it should be noted that students bring also ideas that are compatible with scientific models and can be considered as conceptual achievements, which can be targeted during teaching. Additionally, at a secondary level, teachers should focus on reinforcing and enriching these ideas. The concept of the precursor model seems to play a crucial role in exploring the position of conceptually compatible representations with scientific models in teaching. The precursor model, proposed in the 1990s, integrates aspects from various theoretical perspectives, including science education, Piagetian genetic epistemology, and Vygotskian socio-cultural approaches (Lemeignan & Weil-Barais, 1993; Weil-Barais 2001, 2022). This model aims to bridge the gap between children's naive mental representations and the models of physical sciences, allowing for the construction of intermediate mental schemes within an educational context. These mental entities are aligned with children's developmental abilities while also being compatible with scientific models (Ravanis, 2020; Ravanis & Boilevin, 2022). Recent research in early childhood science education has demonstrated the successful implementation of precursor models across various subjects (Canedo-Ibarra et al., 2012; Delserieys et al., 2018; Lorenzo Flores et al., 2018; Kambouri-Danos et al., 2019). These studies have revealed consistent structural and functional aspects of young children's thinking, enabling them to engage in systematic reasoning when describing and predicting phenomena.

In this perspective, the current study attempts to describe: (a) the elements that a precursor model of preschool children may possess regarding electricity, and (b) how these elements could guide teaching activities about electricity. The term "electricity" is used here in its broader sense, as a standard section in physics. However, its conceptual content for preschool age is a product of didactic transposition and is determined, among other things, through the characteristics of the precursor model described below. It should be noted that for older ages, a connection between electrostatics and electrokinetics is proposed for teaching electricity. Therefore, it is clear that the topic of electricity for preschool children differs from the same-named topic in elementary or middle school. Nevertheless, the authors maintain the use of the term "electricity" as it is also maintained in other educational levels, despite having a different conceptual content. To determine the characteristics of the precursor model, data from three relevant studies that focused on different conceptual dimensions of electricity were utilized (Kada & Ravanis, 2016; Kaliampos et al., 2020; Timpili et al., 2023). Based on these findings, an instructional framework is being proposed for the development of teaching activities.

PRECURSOR MODEL ON ELECTRICITY

The aforementioned studies aimed to investigate the construction of precursor models in the thinking of young children (Ravanis et al., 2022). Children who took part in all the studies were between 5 and 6 years old and were randomly selected from those who were willing to participate. They all came from the same middle socio-economic background and attended kindergarten classes in an urban area in Greece (Patras). In detail, in study (a), 108 children participated (Kada & Ravanis, 2016), in study (b), 131 children participated (Kaliampos et al., 2020), and in study (c), 16 children participated (Timpili et al., 2023). None of them had previously received any formal instruction or engaged in discussions or tasks related to the specific topic. All the children volunteered to be part of the study after being asked if they wished to talk to the researcher. Consent was obtained from their parents and the study was approved by the ethics committee of the Department of Educational Sciences and Early Childhood Education at the University of Patras. The convenience sample included children with varying levels of performance (low, medium, and high). In all the studies, the children were asked questions and given tasks related to everyday electrical phenomena, simple electrical circuits, and electrical appliances. Data for the studies were collected through individual semi-structured interviews. These interviews lasted approximately 20 minutes each and were conducted in a specially designated area within the kindergarten. The interviews were carried out by the researchers and nonverbal observations were recorded during the interviews.

In the first study (a), the focus was on constructing a simple electrical circuit, understanding its components and comprehending the role of the battery. The second study (b) explored how the children understand the term 'electricity', children's reasoning about electrical appliances, and their understanding of the components of a simple electrical circuit. The third study (c) examined young children's mental representations of electrical current.

In study (a), children were provided with a battery, cables, and a lamp. They were asked to identify each item and describe how they would interact with them. With assistance as needed, they were then instructed to connect the items in order to light the lamp. Although many children could state the correct way to connect the cables, they encountered difficulties in doing so. After successfully lighting the lamp, a discussion ensued to reflect on the process and emphasize the role of the battery. To facilitate the construction of the simple electric circuit, a base was used, and the children placed the objects on it.

In study (b), children were asked to share their thoughts on electricity, to describe how they can construct a simple electrical circuit similar to study (a) and express their perspectives on electrical appliances and their functioning. The discussions with children regarding electricity and electrical appliances were conducted without the use of additional materials, aiming to capture their mental representations without specific external influences.

Study (c) focused on exploring children's mental representations concerning the conceptualization of electric current, the identification of electricity in familiar surroundings, and the generation and transportation of electricity.

The collected data from the interviews were analyzed, leading to the categorization of children's responses into three distinct levels: compatible with school knowledge, intermediate, and insufficient. This analytical approach, frequently utilized in similar research on young children's mental representations, involves assessing the correspondence between children's responses and the models used in school science. As mentioned, school science is a transposed version of scientific knowledge, while still retaining elements that make it compatible with it. The ensuing discussion revolves around the children's precursor model, encompassing electricity, electric current, electric appliances, electrical circuits, the identification of electricity in the environment, and the generation and transportation of electricity.

A fundamental element of the precursor model derived from the above researches is the formation of a mental representation that acknowledges the existence of an entity capable of producing specific effects, such as lighting or appliance operation. While the verbal expressions used by children to describe this entity may vary, they all serve the purpose of attributing effects to it. Terms like 'electric current', 'current', 'electricity',' etc., unambiguously refer to this entity. In the context of a precursor model for early childhood, these terms do not indicate differentiation as they are not associated with distinct concepts in children's thinking. The only differentiation observed is regarding electric current, which children associate with electrical appliances, particularly those they encounter in familiar environments.

The second element of the precursor model concerns the transportation of electricity, symbolized by a generation point, transmission cables, and a consumption point interconnected with each other. Children seem to grasp the notion of the 'journey' of electric current when represented graphically.

A third crucial element of the precursor model involves recognizing the functional importance of technical components (wires, light bulb, battery) within a simple electrical circuit, as well as their connections. The battery's role as a decisive contributor to the effect is particularly significant. While the role of the light bulb is recognizable and understandable, children's understanding of the battery's role becomes the primary source of energy in the system.

Finally, a fourth important element of the precursor model is the manipulation of specialized technical components (wires, light bulb, battery) to produce an electrical effect. Technological dimensions, as well as psychomotor and cognitive coordination, play a vital role in constructing the precursor model.

TEACHING IMPLICATIONS

The design of appropriate teaching practices related to the precursor model described above undoubtedly acts as an important area of research. From the data of the three studies portrayed above, it became apparent that preschool-age children have the ability to form certain characteristics of the precursor model for electricity at a stage before any instructional influence. The children: a) phenomenologically approach electricity as an entity that causes specific effects, b) perceive it as something that can be transported, c) conceptualize the technical components of an electric circuit, d) construct simple electric circuits. Therefore, these four elements could be considered as learning outcomes and serve as the basic components of a section on electricity in a curriculum for preschool education. It should be noted that these four elements, which are considered desired cognitive achievements by children, have phenomenological character. In other words, the three studies used as a methodological/reference framework showed that the abilities of preschool-age children regarding the conceptualization of electricity are limited to its approach as a physical entity, which they connect with material forms and the material context in which its effects appear.

Indeed, children refer to electricity as something that turns on the light bulb, connects plugs with household appliances, can go from one point to another, and can create a simple electric circuit in which they believe the battery "gets used up" to light the bulb. They do not exhibit the abilities to approach electricity through a mental model that has microscopic characteristics as observed in older ages. Specifically, several researchers emphasize the need for the development of teaching strategies that connect macroscopic level electric phenomena (i.e., electrical attractions and repulsions, intensity of electrical current, voltage of a battery) with the microscopic level theory (i.e., field, potential difference, polarization) (Guisasola, 2013; Psillos et al., 1987). It is emphasized that electrostatic phenomena should be connected with electric current, which in school knowledge usually appear independently of each other. Towards this direction, Sherwood and Chabay (1999) propose a microscopic model according to which the electric circuit is described in terms of concepts of the field and charge. In fact, the above researchers consider that for the teaching of the electric circuit, the concept of the field and charge should be used first, and then, as a pivotal concept, the potential difference. This way, connections are made between the electric field inside the wires and resistors and the potential differences along those elements. Additionally, the function of the battery is to maintain the surface density of charge inside the wire. The adoption of the microscopic model enables the overcoming of students' misconceptions, such as the belief that the potential difference across an open switch, as part of a circuit including a battery, is zero (because $V = IR$, and if $I = 0$, V must be zero). According to the aforementioned microscopic model, the circuit consists of two branches connecting the battery to the open switch. Within these branches, there are positive and negative surface charges present, creating an electric field in the gap between them, which results in an associated potential difference. So, we understand after introducing the concept of potential as a path integral of electric field, we then re-analyze circuits considering potential while still taking into account surface charge and electric field aspects.

For kindergarten children, the approach to learning electricity possesses macroscopic characteristics, which, as elements of the precursor model, according to the above argumentation, should be targeted cognitive outcomes by learners in the design of related activities. These phenomenological elements of the precursor model for electricity are not the starting point of a learning process, but the target. Consequently, the design of teaching activities should emphasize the material context and generally the materiality, as well as the manipulative actions of children on the components of an electric circuit. In other words, learning objectives that are relevant to the precursor model should focus on the technical approach to electricity and the electric circuit and the embodied actions concerning the latter. Towards this direction the STEM (Science, Technology, Engineering, and Mathematics) approach to electricity with an emphasis on embodied thinking can be a more effective choice for the content of teaching activities for preschool-age children compared to more typical approaches that emphasize conceptual deepening.

In STEM education, its disciplines are perceived as a unified entity and their teaching should be integrated and coordinated to address real-world challenges (Sanders, 2009). Barak and Assal (2018) and Lou et al. (2017) propose a definition of STEM education that emphasizes the incorporation of content and skills from science, technology, engineering, and mathematics into the teaching-learning process, not being grounded on any of the frameworks of reference. However, there are also perspectives that perceive STEM as an approach that integrates the knowledge and skills from the four disciplines employing distinct frames of reference (Sanders, 2009). In any case, it is evident that STEM education provides a suitable framework for the convergence of the technical characteristics of electricity as defined by the precursor model, along with the concepts and skills presented by science education. Actually, science education aims to impart scientific practices and inquiry skills to children while also creating opportunities for them to develop interpretive models for concepts and phenomena in the natural world. The latter goal involves the construction of precursor models, which incorporate elements compatible with scientific models. Thus, science education cultivates skills and practices in learners, including observation, questioning, hypothesis formulation, prediction, planning and conducting investigations, data analysis and interpretation, constructing explanations, and communicating information (Bybee, 2014; Gelman, 2009; Worth & Grollman, 2003). Skills which are also essential targets of technology and engineering education. Therefore, adopting a STEM approach to teaching electricity is the most suitable, as it encompasses the phenomenological aspects of the precursor model for electricity, bridging the goals of science and technology education.

Indeed, in the context of STEM education for preschool-aged children, electricity is approached macroscopically through content related to how electric current travels through towns, heats up a toaster, runs an electric motor, and lights up a light bulb. In other words, it is approached phenomenologically, in accordance with the precursor model, for the transfer and effects of electricity, in a way that explicitly relates to real life (Torres-Crespo et al., 2014). Similarly, a phenomenological approach is employed to explore concepts like making by mixing suitable substances and utilizing conductive dough, along with conducting experiments using basic materials like balloons to generate electrostatic phenomena. The teaching approaches used aim to recognize electricity as a technological artifact rather than focusing on the development of interpretive models at a microscopic level (Torres-Crespo et al. 2014). Indeed, in several educational programs for young children that deal with electric circuits, the objectives are related to connecting batteries, closing an electrical circuit, and making a bulb lighting, rather than interpreting these concepts based on the idea of moving charges at a microscopic level; namely, on more typical interpretive models of the natural sciences. Such teaching approaches aim to help children understand in ways that are meaningful to them (Deaton, 2017) as the precursor model described in this study proposes.

In addition to the STEM approach, the emphasis on embodied thinking can constitute the second characteristic for developing activities based on the precursor model for electricity in preschool education. In general, research has shown that educating students in the embodied 'language' of the laboratory is an important stage in the process of concept formation in science learning (Roth & Welzel, 2001). The bodily actions on objects, such as the elements of an electric circuit and any kind of construction that requires electrical connections, as well as the iconic and deictic gestures that emerge during learners' engagement with material objects and devices, are parts of their thinking that contribute to the development of their mental models at a later time, even in subsequent stages of schooling (Roth & Lawless, 2002). For example, the study by Zacharia et al. (2012) demonstrated that embodied actions involving object manipulation for the phenomenon of mechanical equilibrium lead to learning improvements in preschool-aged children compared to actions involving simulations, provided that children start from a state of insufficient conceptual content regarding the phenomenon. Even for phenomena from the microcosm, such as the particulate nature of matter and the connection between temperature and molecular motion, the physical activation of children leads to learning improvements (Hadzigeorgiou, 2002).

Concerning electricity, gestures can serve as factors of expression for ideas as demonstrated by Callinan (2016) in a study with children aged 7, 11, and 14 years old. Specifically, the children used gestures to show the paths that the wires should follow and where the light bulb should be placed when drawing a circuit. Gestures depicted the flow of electricity, expressed the children's predictions of whether the light bulb would light up in a given circuit connection, or conceptualized objects without using verbal speech. Especially the younger children (7 years old) frequently used gestures to represent objects and actions related to the characteristics of the material framework (e.g., circuit connections, light bulbs). We could, therefore, assume that for preschool-aged children, there is compatibility between the development of embodied thinking in such a direction and the characteristics of the precursor model, which, as mentioned, refers to the external-morphological aspects of the electricity. It is evident that there is a difference between the school knowledge proposed for electricity for older ages, based on a microscopic model, and the school knowledge proposed for preschool, as expressed by the specific precursor model. The knowledge for kindergarten relies more on the perception and understanding of using technical artifacts and, in general, spatial entities, as well as the embodied interaction of children with them. However, at present, we lack data to suggest that this approach may lead to a microscopic understanding of electricity for preschool children and further research in this direction is required.

REFERENCES

Alwan, A. (2011). Misconception of heat and temperature among physics students. *Social and Behavioral Sciences, 12*, 600-614.

Barak, M., & Assal, M. (2018). Robotics and STEM learning: Students' achievements in assignments according to the P3 Task Taxonomy-practice, problem solving, and projects. *International Journal of Technology and Design Education, 28*(1), 121-144.

Bergsten, C., Jablonka, E., & Klisinska, A. (2010). A remark on didactic transposition theory. In C. Bergsten, E. Jablonka & T. Wedege (Eds.), *Mathematics and mathematics education: Cultural and social dimensions*. *Proceedings of MADIF 7: The Seventh Swedish Mathematics Education Research Seminar* (pp. 58-68). Linköping: Svensk Förening för Matematik Didaktisk Forskning.

Bybee, R. W. (2014). NGSS and the next generation of science teachers. *Journal of Science Teacher Education, 25*(2), 211-221.

Callinan, C. J. (2016). Talking about electricity: The importance of hearing gestures as well as words. In N. Papadouris, A. Hadjigeorgiou & C. Constantinou (Eds.), *Insights from research in Science teaching and learning. Contributions from Science Education research* (v. 2., pp. 107-120). Springer, Cham.

Canedo-Ibarra, S. P., Castelló-Escandell, J., García-Wehrle, P., & Morales-Blake, A. R. (2010). Precursor models construction at preschool education: An approach to improve scientific education in the classroom. *Review of Science, Mathematics and ICT Education, 4*(1), 41-76.

Chevallard, Y. (1985). *La Transposition Didactique : Du savoir savant au savoir enseigné*. Grenoble: La Pensée Sauvage.

Deaton, C. C. (2017). From static to circuits: Inquiry-based STEM explorations of electricity. *Young Children, 72*(3), 89-93.

Delegkos, N., & Koliopoulos, D. (2020). Constructing the "energy" concept and its social use by students of primary education in Greece. *Research in Science Education, 50*(2), 393-418.

Delserieys, A., Jegou, C., Boilevin, J.-M., & Ravanis, K. (2018). Precursor model and preschool science learning about shadows formation. *Research in Science and Technological Education, 36*(2), 147-164.

Fleer, M. (1991). Socially constructed learning in Early Childhood Science Education. *Research in Science Education, 21*, 96-103.

Gelman, R., Brenneman, K., Macdonald, G., & Román, M. (2009). *Preschool pathways to Science (PrePS [TM]): Facilitating scientific ways of thinking, talking, doing, and understanding*. Brookes Publishing Company.

Glauert, E. B. (2009). How young children understand electric circuits: Prediction, explanation and exploration. *International Journal of Science Education, 31*(8), 1025-1047.

Guisasola, J. (2013). Teaching and learning electricity: The relations between macroscopic level observations and microscopic level theories. In *International Handbook of research in History, Philosophy and Science teaching* (pp. 129-156). Dordrecht: Springer Netherlands.

Hadzigeorgiou, Y. (2002). The utilization of sensori-motor experiences for introducing young pupils to molecular motion: A report of a pilot study. *Physics Education, 37*(3), 239-244.

Kada, V., & Ravanis, K. (2016). Creating a simple electric circuit with children between the ages of five and six. *South African Journal of Education, 36*(2), 1-9.

Kaliampos, G., Kada, V., Saregar, A., & Ravanis, K. (2020). Preschool pupils' mental representations on electricity, simple electrical circuit and electrical appliances. *European Journal of Education Studies, 7*(12), 596-611.

Kalogiannakis, M., & Lantzaki, A. (2012). Teaching electricity in preschool education: A dilemma under negotiation with the use of ICT. *Exploring the World of Child, 11*, 11-21 (in Greek).

Kambouri-Danos, M., Ravanis, K., Jameau, A., & Boilevin, J.-M. (2019). Precursor models and early years Science learning: A case study related to the mater state changes. *Early Childhood Education Journal, 47*(4), 475-488.

Kariotoglou, P., Psillos, D., & Vallasiades, O. (1990). Understanding pressure: Didactical transposition and pupils' conceptions. *Physics Education, 25*, 92-96.

Lemeignan, G., & Weil-Barais, A. (1993). *Construire des concepts en Physique*. Paris: Hachette.

Lorenzo Flores, M., Sesto Varela,V., & García-Rodeja, G. (2018). Una propuesta didáctica para la construcción de un modelo precursor del aire en la Educación Infantil. *Ápice. Revista de Educación Científica, 2*(2), 55-68.

Lou, S.-J., Chou, Y.-C., Shih, R.-C., & Chung, C.-C. (2017). A study of creativity in CaC2 steamship-derived STEM project-based learning. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(6), 2387-2404.

Martinand, J. L. (1989). Pratiques de référence, transposition didactique et savoirs professionnels en sciences et techniques. *Les Sciences de l'Education, 2*, 23-29.

Psillos, D., Koumaras, P., & Valassiades, O. (1987). Pupils' representations of electric current before, during and after instruction on DC circuits. *Research in Science & Technological Education, 5*(2), 185-199.

Ravanis, K. (2020). Precursor models of the Physical Sciences in Early Childhood Education students' thinking. *Science Education Research and Praxis, 76*, 24-31.

Ravanis, K., & Boilevin, J.-M. (2022). What use is a precursor model in early science teaching and learning? Didactic perspectives. In J.-M. Boilevin, A. Delserieys & K. Ravanis (Eds.), *Precursor models for teaching and learning Science during early childhood* (pp. 33-49). Springer.

Ravanis, K., Kaliampos, G., Arnantonaki, D., & Pantidos, P. (2022). The axes of a Precursor Model for Electricity in the thinking of 5–6-year-old children. In J.-M. Boilevin, A. Delserieys & K. Ravanis (Eds.), *Precursor Models for teaching and learning Science during early childhood* (pp. 155-168). Springer.

Roth, W.-M., & Welzel, M. (2001). From activity to gestures and scientific language. *Journal of Research in Science Teaching, 38*(1), 103-136.

Roth, W.-M., & Lawless, D. (2002). Signs, deixis, and the emergence of scientific explanation. *Semiotica, 138*(1/4), 95-130.

Sanders, M. (2009). STEM, STEM education, STEMAnia. *The Technology Teacher, 68*(4), 20-27.

Sherwood, B. A., & Chabay, R. W. (1999). *A unified treatment of electrostatics and circuits*. Retrieved from https://matterandinteractions.org/wp-content/uploads/2016/07/circuit.pdf.

Solomonidou, C., & Kakana, D.-M. (2000) Preschool children's conceptions about the electric current and the functioning of electric appliances. *European Early Childhood Education Research Journal, 8*(1), 95-111.

Timpili, D., Kaliampos, G., & Ravanis, K. (2023). Representations of children 5-6 years old about electric current: A qualitative approach. *Journal of Educational Technology and Instruction, 2*(1), 1-14.

Torres-Crespo, M. N., Kraatz, E., & Pallansch, L. (2014). From fearing STEM to playing with it: The natural integration of STEM into the preschool classroom. *SRATE Journal,* 23(2), 8-16.

Weil-Barais, A. (2001). Constructivist approaches and the teaching of science. *Prospects, 31*(2), 187-196.

Weil-Barais, A. (2022). What is a precursor model? In J.-M. Boilevin, A. Delserieys & K. Ravanis (Eds.), *Precursor models for teaching and learning science during early childhood* (pp. 11-32). Springer.

Worth, K., & Grollman, S. (2003). *Worms, Shadows and Whirlpools: Science in the early childhood classroom*. Portsmouth, NH: Heinemann.

Zacharia, Z. C., Loizou, E., & Papaevripidou, M. (2012). Is physicality an important aspect of learning through science experimentation among kindergarten students? *Early Childhood Research Quarterly, 27*(3), 447-457.

Zoupidis, A., Spyrtou, A., Pnevmatikos, D., & Kariotoglou, P. (2021). Teaching and learning floating and sinking: Didactic transformation in a density-based approach. *Fluids, 6*(4), 158.