The physical sciences in early childhood education: Theoretical frameworks, strategies and activities

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Abstract. This paper deals with the different theoretical frameworks used for the initiation of early childhood students to the physical sciences. We present in general four distinct frameworks as well as typical examples of their teaching approaches. The empiricist trends are mainly involved in the effort to transmit knowledge of science, connect new experiences with the children’s old experiences, and exhibit and present experiments. The theoretical and methodological framework of the second category of research and deployment activities is Piagetian genetic epistemology. Within this framework, children are offered opportunities to assimilate physical knowledge through experimentation and the manipulation of specially constructed, selected, and organized teaching materials and environments. In the socio-cognitive approach, one can classify activities that are influenced by post-Piagetian and/or by Vygotsky's learning theories as well as by the results of research in Science Education, which in general recognize the importance and the privileged role of student’s mental representations, and of social interaction in the implementation of new cognitive operations. Finally, in the socio-cultural perspective of Vygotsky on the basis of which learning is the product of the holistic social, cultural and historical horizon of the student, the approach of concepts and phenomena of physical sciences is attempted through daily activities familiar to young children.

1. Introduction
Over the last thirty years in different fields of educational research, such as Science Education, Educational and Developmental Psychology and Early Childhood Education, there has been a growing interest in building physical knowledge in the thought of 4-8-year-olds. Diverse theoretical starting points and multiple epistemological orientations often led research in parallel paths. Furthermore, it produced confusion during the implementation of programs or the educational activities in the classroom. However, over time, the interactions between the different currents and trends created a common reference space known as Early Childhood Science Education. Within this area appears a wide range of questions and topics of research and theory. Among them, the most stable axis seems to be the one related to the processes of detecting and learning the properties of physical objects and materials, the phenomena and concepts of Physical Sciences.

In this important axis, ever since the 90's the approach and analysis of a wide range of curricula, empirical research, and proposals for teaching activities, has led to a classification whose scope and characteristics are evolving and expanding [1, 2, 3]. Key elements in the formation of this classification were: the learning theory that dominates the teaching approach, the role and practices of teachers during
teaching activities and the way young children are placed in the learning situation. A systematic crystallization of different trends led to four distinct frameworks of learning and development activities to introduce young children to the world of Physical Sciences: the empiricist, the Piagetian, the socio-cognitive and the socio-cultural or cultural-historical approach. Regardless, this distinction is schematic as both their orientation as well their historical formation have peculiarities that do not allow an epistemological equivalence.

In the following we will present in general the four distinct frameworks as well as typical examples of their teaching approaches.

2. The empiricist tradition

The origin of the empiricist tradition is beyond the current research horizons. In the basic foundations of this approach, we find a number of influences: the historical currents of preschool pedagogy in which the role of providing experiences to children was decisive, early behaviorism with the focus on the importance of stimuli, and the traditional perception of teaching and learning of the Physical Sciences at the center of which is the knowledge of science itself. All of these influences are not an organized theory, but create an implicit and non-formulated framework with clear pedagogical features. The learning of Physical Sciences is a matter of good organization in the “transfer” of knowledge from teachers to students and the creation of learning environments with rich stimuli. These include work in the laboratory.

In this context, the content of teaching activities is selected through processes of simplification using scientific knowledge itself, while the role of the teacher is central to the learning process as it must be the “strong pole” of an asymmetric pedagogical relationship. Thus, subjective views on the appropriateness of teaching objects for young children prevail, both on the part of the creators of the activity programs and on the part of the teachers. Since the teacher is at the center of such activities, he/she selects and presents the reference knowledge, guides the children based on his/her plan, distribute the tasks, asks questions, and processes the answers. In such an educational environment, young students are asked to follow the teacher and his/her initiatives, to participate in what is asked of them, to have passive perceptual participation, and often to ask, discuss or repeat the experiments or procedures that they saw. Of course, due to the epistemological ambiguity of the context, there are often influences in this approach from other theoretical currents which appear erratically with references to “scientific skills”, “attitudes” or “science inquiry” [4, 5, 6]. However, these references are usually procedural as when their implementation is attempted, the general framework commitments do not allow for in-depth development.

The example of an activity for light and shadows is typical. “Back in February, Mrs. O’Shea’s preschool children had explored the concept of light and shadows. They collected many types of materials to see which ones would create a shadow in the bright light and which ones the light would just pass through. After several days of experimentation, they realized that while opaque materials create shadows and transparent materials allow light to pass through easily, there are some things that don’t fit either category. These materials allow some light to pass through (although not as much as window glass) and they cause very light shadows. Later in the school year, a visitor to the classroom was present during snack time when the children were trying new clear strawberry flavored Jello with stars and moon shapes in it. The visitor overheard the following conversation among the four year-olds: ‘It’s transparent!’ remarked one little girl with surprise. ‘No, it’s translucent,’ countered another girl. ‘Why do you say it’s translucent?’ asked Mrs. O’Shea. ‘Because you can only see through it a little,’ the girl responded” [7, p. 12].

In the context of experimenting with light and shadows, the center of gravity is not in the difficulties of children, which revolves around understanding light as an entity [8] and creating shadow due to the obstruction of light [9], but to teach children to distinguish empirically what it is transparent or opaque objects.
3. A Piagetian framework: a precursor research trend

In the general context of Piagetian Genetic Epistemology, it is known that the construction of the world in the child's mind is a gradual progressive process. The development of intelligence is not a simple recording of sensory data that expands with biological maturation, but a complex process of creating evolutionary structures whose construction is directly related to the activity of the developing children and the interaction with the world around them. From this perspective researchers of Pedagogy who accept the Piagetian theoretical framework [10, 11, 12] “suggested a turn to physical-knowledge activities which focus on children’s activity with the pedagogical material and generally the objects at its disposal with which to interact. This choice is entirely distinguishable from the teaching of science, which focuses on theories, models, laws and experimental methodology. During physical-knowledge activities, choices and action patterns, individual and team work, the children’s ordinary difficulties and insurmountable obstacles are the subject of study at the research level and the subject of a teaching intervention at the level of pedagogical practices” [3, p. 285]. Effective work with young children would, therefore, require an educational environment in which children's initiative is favored as much as possible. Teachers identify the topic, they set the desired aims, and prepare the materials that the children will handle, moving them, transforming them, and combining them in order to implement their own plans. During the activity, the teacher monitors the children's actions, supports their choices, helps them to expand the plans they make, faces the insurmountable obstacles, and carefully records what he observes. These recordings are useful to identify weaknesses in the design, materials, and capabilities of children and to adapt accordingly.

An interesting example in the context of the Piagetian strategy is the development of activities in order to introduce kindergarten children to the elementary magnetic properties. The children who agreed to ‘play’ worked in small groups with the teacher. The whole procedure takes place in a small, specially arranged room in the nursery-school. The children of each group worked around a table with their teacher for approximately 20 minutes. Let us examine the structure of the activity. “We gave each group of children a number of disk-like and rod-like magnets, as well as materials some of which are attracted by magnets and some not (little metallic rods, clips, drawing pins, plastic pen caps, small pieces of paper, etc.). These materials were presented one by one by a nursery school teacher at the beginning of the process and handed over to the children for familiarisation. The teacher then asked the children to take the materials on the table and play with them. The children take the initiative and effect various constructions (small airplanes, bridges, etc.) which they characterise as such either on their own initiative or in answer to the teacher's questions. Whenever the children fail at their constructions, the teachers intervene in order to help them execute their plans. Certain subjects, lacking good psycho-motor coordination, are not able to manipulate the materials as they wish, with the result that they encounter practical obstacles which they, at times, cannot overcome by themselves. The teachers also attempted to intervene when the children abandoned their occupation or when they started to play by using the rest of the material without the magnets. Interaction between children was desired, so we allowed and encouraged it. That is, we let the children observe the work of other children and we urged them to cooperate in the creation of a common construction and the exchange of the material they selected” [1, p. 84].

Obviously, children have the full initiative to act with the materials, to plan what they will do, to try to implement their plans, while the teacher monitors the development of the children's actions and intervenes only when he deems that he can help to overcome insurmountable difficulties.

4. Research based contemporary trends

4.1. A socio-cognitive perspective

The issue of children's mental representations of concepts and phenomena relating to the Physical Sciences is perhaps the most important issue of Science Education as an autonomous scientific field. Also, the location of their distance from the scientific models that we formulate and use in education as objects of teaching immediately raises the question of the teaching processes with which we will
overcome any obstacles so that children’s thinking can be transformed [13, 14, 15]. In the socio-cognitive approach, one can classify activities that are influenced by post-Piagetian learning theories and/or by Vygotsky’s theory as well as by the results of research in Science Education, which in general recognize the importance and privileged role of social interaction in the implementation of new cognitive operations and learning. The teacher as tutor and/or mediator intervenes between scientific knowledge and practices on the one hand and the problems of representative thinking in young children on the other. Children in such a design are actively called to function in environments specifically designed to help overcome their difficulties. Within this theoretical framework, we formulate activities for scientific initiation at the age of 4-8 years, which aim at destabilizing and/or reformulating the naive representations of young pupils. The proposed activities are the products of specific prior research, based on quite classical methodological planning (pre-test, in vitro teaching interventions, post-test, quantitative analyses of the differences between pre and post-test, qualitative analyses of the exchanges and interactions between adults and children during the interventions, evaluation and in some cases, in vivo didactic interventions and corresponding qualitative and quantitative analyses). This procedure attempts to answer the question of the effectiveness of interventions and didactic interactions that aim at overcoming the difficulties of young pupils [2].

A typical example of a socio-cognitive strategy is the structure of a research project implemented with kindergarten children on the issue of water status changes. The activity included eight separate phases with four different state change phenomena. For each situation, the children were asked to make a prediction before the experiment and after an explanation. In the first phase, the children were presented with ice cubes that had just come out of the fridge. Predictions were made about what would happen if we heated them in the fire. In the second phase, the ice cubes were placed in the flame of camping gas. After the melt, the children discussed what happened based on their predictions in the first stage. In the third phase, the children were asked to predict what would happen if we heated a part of the water formed by the ice cubes. In the fourth phase, the water is placed in the camping gas flame and the water is evaporated. After the ventilation, the children discussed what happened based on their predictions in the third stage. In the fifth phase, water remaining from the melting of the ice cubes heated in the camping gas flame. Here children are asked to predict what will happen if an icy plate is placed over the water vapor. In the sixth phase, the dish that comes out of the refrigerator is placed in the course of water vapor, the water vapor is liquefied and a small amount of water is collected. After the liquefaction, the children discussed what happened based on their predictions in the fifth phase. In the seventh phase, the children were asked to predict what would happen if we put the water we collected during the liquefaction in the freezer. Finally, in the eighth phase, the water is placed in the freezer and a little later it is found that it has become ice. After coagulation, the children discussed what happened based on their predictions in the seventh phase [16].

During the discussions on the four phenomena, the interaction with the children aims to direct their thoughts and reasoning towards the relation of the changes in the water’s physical state with the cooling or the heating.

4.2. *A socio-cultural perspective*

In recent years, a basic hypothesis of Vygotsky on the basis of which learning is the product of the holistic social, cultural and historical horizon of children has occupied an important place in the field of education [17]. This current, which we often encounter in the literature as “socio-cultural” and/or “cultural-historical” with different perspectives, has also had an impact on Early Childhood Science Education. In such a context, the main stake in the pedagogical environment is not knowledge itself, but the processes through which knowledge acquires real meaning. Of course, it is not at all easy for classical research to move to such a perspective, as in addition to the change of theoretical requirements, a total methodological shift towards exhaustive and flexible qualitative approaches is necessary. In a socio-cultural context the findings of previous approaches are local, static and sought in specific circumstances. On the contrary, the exploration and elaboration of scientific concepts and phenomena in the conditions of everyday reality and life, allows the better understanding and deeper
conceptualization of the context, but also highlights the teacher as a cultural mediator [18, 19]. Trying to systematize the basic elements of this framework we can distinguish two dimensions: “a) at the level of research, to understand how children approach Physical Science concepts and phenomena in a dialectic relationship with cultural, social and physical elements of the environment; and b) at the level of didactic procedures, to create conditions for the coordination between a personal intellectual progress and the situational characteristics that appear in a collective scientific experience in school. In such a perspective, the teacher organizes and supports a communication framework and a school environment which allows the emergence and exploitation of elements from overall human activity. The pedagogical material and the structure of the teaching activities allow the simultaneous emergence of the intellectual (cognitive, imaginary, etc.), affective, bodily, and social parameters of the situations unfolding in the classroom. Children develop initiatives, they are continuously interacting and communicating with their classmates and teachers, using the materials in many ways, playing symbolic games in which they take on roles and thus approaching the physical world from different paths” [2, p. 286].

In this direction, “conceptual play” is often used as a framework for the development of activities. It is a theoretical and methodological conception in which the coupling of fantasy and reality allows the involvement of children, among other teaching subjects, with the approach of Physical Sciences. In the playful activities carried out in this context, children use objects, materials, and substances to which they have given a specific symbolic meaning. Thus in structured play-based programs children are involved in playful situations and teachers are mediating between children’s play and children’s concept formation [20, 21]. A typical example of such activity was carried out with the aim of conceptualizing “dissolution” [22]. The basic scenario of the play was to try to make a hot drink for a “sick” puppet that was being handled by the teacher-researcher. The activity took place in three phases. In each phase, a different educational scenario was formed which framed each activity. (a) In the first phase, the children are asked to cook soup for the puppet as she "feels very sick". The children are encouraged to enter the classroom dollhouse and experiment with different ingredients in order to cook the soup. The emphasis here was on dissolving the salt in the soup. (b) In the second phase, which took place a few days later, the puppet was “still sick”, so the teacher suggested that the children be given a hot beverage made by the teacher herself. The puppet finds it difficult to drink the beverage and for this reason, the teacher urges the children to find why she does not like it. In the second phase, the solute was sugar and the activity turned to this discovery. (c) In the third phase, the puppet “wants the children to make her another hot beverage”, because she did not like the first one that the teacher had made. Here the teacher presented a white powder (niseste flour), which is the basis for the preparation of beverage. At this stage, children are asked to predict what will happen to the powder if we throw it in the water. The overall activity was designed in such a way that the process makes sense to the children and mobilizes their intentional and active involvement. In an environment where children are emotionally involved in the solution of a problem understood and experienced by themselves or in the family framework, they activate cognitive, mental, and emotional abilities and connect a scientific activity with their daily life. Also, given that children were encouraged to both interact and refer to sources of knowledge, the framework seems to allow for the use of a wide range of teaching supports.

5. Discussion

The classification presented here has a special orientation that offers a rather wide-ranging field of research: the transition from specific theoretical currents regarding the development of the intellect to the implementation of activities for the initiation of young children into the world of Physical Sciences. However, in the context of Early Childhood Science Education, there are other very interesting areas of research that are of great importance for gaining scientific experience: the role of motivation and home components [23] or the relationship between early understanding of science and the sustainability of societies [24]. But by staying within the narrow range of the relationship of theoretical approaches to learning and teaching activities, we can leverage key elements from research into the everyday classroom. Indeed, in each of the four strategies, there are special pedagogical interests.
The empiricist approach is a strong traditional framework without any relation to educational research. As its basic characteristics are implicit, its didactic paths do not have a linear course but rather constitute a range of possibilities with basic structural elements a teacher-centered perspective, and teaching objects in an empirical way drawn directly from science. Compared to other strategies today, it has significant weaknesses, but it is still strong as it offers ease of classroom management, requires limited resources, does not necessitate specially trained teachers and still influences many programs.

Piagetian strategy on the one hand is based on strong learning theory and on the other hand, focuses on the child's own activity. However, the commitment of active handling of materials by young children pushes the strategy to its limits, as an initiation into the Physical Sciences often requires materials that are not completely safe for children's hands. Also, at a time when the issue of didactic-social interactions is central to teaching and learning, in the Piagetian perspective it is degraded since the issue of individual construction of knowledge is raised. The resulting problems, combined with the large resources required by space, time, materials, and teacher training, have greatly reduced its scope.

Socio-cognitive approaches provide a solid ground for research and development activities. Both from a theoretical and methodological point of view, there is a multi-year experience that allows the creation of a safe workplace with satisfactory results in Early Childhood Science Education as well. In fact, in recent years some of the relevant efforts have been directed not only to the study of the transformation of mental representations but to the formation of precursor models in the thinking of young children, i.e. cognitive entities whose fundamental elements are compatible with those of the scientific models used in the processes of learning and teaching Physical Sciences [2, 3, 9, 16]. However, the socio-cognitive perspective, despite its undeniable dynamics allowing systematic and effective changes in children's thinking, has systematic limitations as it refers closely to the exploitation of didactic interventions.

It is precisely this narrow view that socio-cultural perspectives seem to address. By opening the field of research and classroom activity to the broader cultural and wider social contexts, these become reference frameworks for communication around specific learning objectives. Thus, it shifts the center of gravity from the narrow field of cognitive transformations to the transition from individual teacher-mediated cognitive development to the wider area of cultural and social semiotic systems. Of course, the breadth and openness of such educational environments, in which elements such as imagination, play, body, space of action are involved, always have the risk of degenerating the aims of teaching and vagueness in the learning outcome.

The attempt to classify the elements of a very wide and continuous spectrum of learning phenomena in the field of Early Childhood Science Education inevitably bears the risks of artificial shaping. However, it can offer some support both for understanding what and why is happening in research and teaching practice and for designing fruitful and effective teaching interventions. Finally, it would be of particular interest to study whether the elements of such a classification can illuminate the practices, quests, and needs of teachers. Currently, a new stream of research is moving in this direction.

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