REVISTA ELECTRÓNICA DE INVESTIGACIÓN
EN EDUCACIÓN EN CIENCIAS
ISSN 1850-6666

Número especial - 20 Años REIEC

The concept of Cognitive Conflict in Science Education: structural and functional aspects

Konstantinos Ravanis

ravanis@upatras.gr

Department of Educational Sciences and Early Childhood Education, University of Patras, Greece

Abstract

This article approaches the concept of cognitive conflict from a two-dimensional perspective: the first concerns the study of the structural elements of the concept, and the second involves identifying the functional characteristics of cognitive conflict in Science Education research and in teaching practices for learning and teaching Natural Sciences. In this dual orientation, cognitive conflict is defined, distinguished from other related concepts, and differentiated from concepts that create misunderstandings. The types of cognitive conflict (simple, operational, and socio-cognitive conflict) are also presented, and relevant examples are provided.

Keywords: Cognitive conflict**,** Science Education, simple, operational, and socio-cognitive conflict

El concepto de conflicto cognitivo en la enseñanza de las ciencias: aspectos estructurales y funcionales

Resumen

Este artículo aborda el concepto de conflicto cognitivo desde una perspectiva bidimensional: la primera se centra en el estudio de sus elementos estructurales y la segunda en la identificación de sus características funcionales en la investigación en Educación en Ciencias y en las prácticas docentes para el aprendizaje y la enseñanza de las Ciencias Naturales. En esta doble perspectiva, se define el conflicto cognitivo, se distingue de otros conceptos relacionados y se diferencia de aquellos que generan malentendidos. También se presentan los tipos de conflicto cognitivo (simple, operacional y sociocognitivo) y se proporcionan ejemplos relevantes.

Palabras clave: Conflicto cognitivo, Educación en Ciencias, conflicto simple, operacional y sociocognitivo

Le concept de conflit cognitif dans l'enseignement des sciences : aspects structurels et fonctionnels

Résumé

Cet article aborde la notion de conflit cognitif sous deux angles : la première consiste à étudier les éléments structurels du concept et la seconde à identifier les caractéristiques fonctionnelles du conflit cognitif dans la recherche en sciences de l'éducation et les pratiques pédagogiques pour l'apprentissage et l'enseignement des sciences naturelles. Dans cette double orientation, le conflit cognitif est défini, distingué d'autres concepts apparentés et différencié des concepts qui prêtent à confusion. Les types de conflits cognitifs (simple, opérationnel et socio-cognitif) sont également présentés et illustrés par des exemples pertinents.

Mots clés: Conflit cognitif, didactique des sciences, conflit simple, opérationnel et socio-cognitif

O Conceito de Conflito Cognitivo no Ensino de Ciências: Aspectos Estruturais e Funcionais

Resumo

Este artigo aborda o conceito de conflito cognitivo a partir de uma perspectiva bidimensional: a primeira concentra-se no estudo de seus elementos estruturais e a segunda na identificação de suas características funcionais na pesquisa em ensino de ciências e nas práticas de ensino e aprendizagem das ciências naturais. A partir dessa dupla perspectiva, o conflito cognitivo é definido, distinguido de outros conceitos relacionados e diferenciados daqueles que geram mal-entendidos. Os tipos de conflito cognitivo (simples, operacional e sociocognitivo) também são apresentados, e exemplos relevantes são fornecidos.

Palavras-chave: Conflito cognitivo, Ensino de ciências, conflito simples, conflito operacional, conflito sociocognitivo.

1. INTRODUCTION

Science Education, as it has emerged over the last 50 years as an autonomous scientific field, has been in interaction with both the Epistemology of cognitive development and Psychology focused on learning. Indeed, questions related to learning and teaching issues, such as analogies and metaphors, on the one hand have a clear developmental dimension, while on the other hand they become tools for teaching mediation. In any case, it is obvious that since Science Education always focuses on the development of children's thinking, it is obvious that it must make use of research findings on learning issues, based on which we can interpret, rather than simply describe, the difficulties, and make efforts to formulate strategies that will transform children's cognitive structure and functioning.

A characteristic concept that is also the subject of study and work in various scientific approaches is the concept of 'cognitive conflict'. As a conflict at the level of cognition, we define, at first glance, any situation in which the predictions, assumptions, focuses, or assessments we make in order to address an issue, question, or problem are refuted or challenged in ways that causes cognitive dissonance or destabilization.

During the conflict resolution process, the arguments generated by initial predictions, assumptions, focuses, or assessments become subjects of reflection. So, once thought becomes destabilized, it follows certain paths in order to regain balance. Thus, the scope of the reasonings used so far is limited to addressing only certain issues, or they are abandoned and replaced by others that are considered more functional and effective.

This issue was perhaps first raised in a theoretical context by J. Piaget (1975). Here, the hypothesis that cognitive development is a continuous interaction between assimilation, as a process of integration into mental schemata that are in equilibrium in thought, and accommodation, as a process of modifying these schemata to assimilate new entities and change the level of equilibrium, automatically raises the question of the mechanism that leads to accommodation. The answer to this question relies on the cognitive destabilization of initial thought schemata "induced by awareness of contradictory, discrepant, 'non assimilable' data" (Flavell, 1977, p. 242).

Cognitive conflict is, in fact, a simple idea that has been systematized by research in the psychology of learning and the epistemology of knowledge in the search for techniques to overcome obstacles to understanding, an idea that is also often used empirically by educators in their efforts to help children understand. Indeed, everyday educational practices can help reveal the constructive role they can play in learning, creating teaching conditions that lead children to formulate arguments that result in apparent inconsistencies with the results of some experimental procedures or theoretical estimates or calculations. In fact, teaching Natural Sciences is a prime area for creating conflicting learning situations, since it is usually based on experimental activities that require the formulation of hypotheses or at least some predictions, which are often refuted and thus create conditions for reflection (Ravanis & Papamichaël, 1995; Ravanis, Papamichaël & Koulaidis, 2002; Skoumios, 2009, 2018; Trumper, 1997).

However, any imbalance, destabilization or instability in thinking does not necessarily lead to cognitive conflict (Dreyfus, Jungwirth & Eliovitch, 1990; Zittoun, Perret-Clermont & Carugati, 1997).

2. LEARNING ISSUES IN THE DEVELOPMENT OF COGNITIVE CONFLICT PROCESSES

Learning and teaching processes that aim to create cognitive conflicts are not always capable of influencing students' thinking in such a way as to lead to a revision of their initial patterns of understanding and reasoning. Often children fail to recognize what cognitive conflict consists of, as they do not associate two opposing estimations as we would expect, or they ignore certain conflicting parameters, while in other cases they simply accept the conflict as a paradox without seeking further clarification (Bovet, Parrat-Dayan & Vonèche, 1988; Murray, 1983). Even when intended cognitive conflicts appear effective to science teachers or science education researchers, it is uncertain whether they correspond to the expected cognitive transformations and, therefore, to a new understanding of the phenomena under consideration.

Research efforts that attempt to examine more deeply the results of cognitive conflicts have shown that these can offer children the opportunity to acquire new knowledge, but they do not have a transformative effect on the logical patterns of dealing with reality, such as causal reasoning (Smedslund, 1966). Karmiloff-Smith (1992) also found that children often do not address certain observations that cannot be explained on the basis of what they already know, as data that could lead to cognitive conflict. Frequently, when the results of their activities do not lead to what is expected by the children themselves, they ignore, misinterpret, or bypass these results without consequences for their cognitive organization. Another possibility recorded in the study (Karmiloff-Smith, 1992) is the construction in children's thinking of certain personal 'axioms', which, although not explicitly stated, form the basis for the development of reasoning that, despite being contradictory in adult thinking, seems reasonable to children and is selectively adopted for use in different circumstances. Thus, conflicting reasonings coexist and, since there is no question of choosing between them, we cannot claim that the conflictual process has brought about any transformation.

These findings lead us to search for variables that allow children's developing thinking to be aware of cognitive conflicts. Thus, at the level of teaching practices, the effort to create and exploit cognitive conflicts is not a general learning strategy that is activated when we create circumstances of conflicting observational data or reasoning, but rather a possibility and an opportunity.

Hewson and Hewson (1984) identified the conditions under which children are led to recognize cognitive conflicts and formulated the possible outcomes of these cognitive conflicts. For children to be able to determine that two conceptualizations are in conflict, it is necessary that they:

1) Understand these reasoning processes.
2) Have formulated in their minds the necessary parameters that allow for the comparison of the two conflicting arguments.

These criteria raise the issue of the conditions for creating a teaching space within which it would be possible to create conditions for cognitive conflict. In the rest of this section, we will outline the key characteristics of three situations that aim to create cognitive conflicts. The first tends to meet both criteria of Hewson and Hewson (1984), while the other two do not seem to meet one of the two criteria.

2.1. Situation 1: How do nails get rusty?

We choose to begin our presentation of examples of cognitive conflict with a simple situation, such as the oxidation of a metal, to emphasize that this concept is not necessarily related to complex experimental and/or mental processes and that we can create suitable conditions for destabilizing students' thinking in the laboratory or classroom, even with very simple situations or contrasting arguments. We also emphasize that the processes through which conflicting situations arise do not complete the desired intellectual formation of new knowledge but create the critical condition for the activation of learning potential.

During the study of explanations given by 13-14-year-old students about the origin of rust on the surface of metal nails, it was found that children do not associate the phenomenon with what they already know about chemical changes. In fact, some children expressed the opinion that the rust already existed beneath the surface of the nail and appeared on the surface during oxidation (Driver et al., 1994; Keeley & Tugel, 2009). Specifically for those children who expressed this reasoning, the teachers proposed a simple experiment in order to explore with the students what happens inside a nail. Cutting a rusty nail vertically, they noticed on the circular surface of the cut that the rust was only on the outer surface, while the metal inside retained its shine.

However, creating a contradiction between the children's initial estimation of the origin of rust and the conclusion they reached did not simply provide them with information or an image of the situation that they had not had access to until that moment. This contradiction creates the conditions for guiding children's thinking towards an approach to the phenomenon of oxidation that does not allow rust to be recognized as a pre-existing substance that is revealed beneath the surface by some mechanical process (a process that proceeds 'from the inside - to the outside'). Instead, it leads to the formulation of a causal argument to describe the alteration of the nail surface (a process 'from the outside - to the inside').

As we have seen, the context of experimentation favors a conflict created here by two opposing lines of reasoning. However, in order to become a truly effective cognitive conflict, i.e., a satisfactory learning process in the context of science teaching, it must be incorporated into lessons that explain metal oxidation, i.e., within the teaching process of the appropriate relevant school science model. Therefore, the process 'from the outside - to the inside' process makes sense in the students' thinking as long as it is part of understanding the chemical process that takes place, and only then does the pursuit of creating conditions for cognitive conflict make sense in the school context.

2.2. Situation 2: The temperature of a material during a change of state

As we know, during a change in the state of a material, for example during melting, evaporation or liquefaction, the temperature of the material remains constant either by supplying or extracting heat. The possibility of interpreting the phenomenon of state change requires reasoning based on an understanding of the utilization of supplied or absorbed energy through heat at the microscopic level. It is precisely this condition that makes it difficult for empirical thinking to approach the phenomenon of temperature stability during a change of state, given that the empirical mental representations conceptually manipulated by the child create obstacles. For example, most elementary or middle school children believe that when we heat a quantity of water, its temperature will increase continuously (Ravanis, 2013), without being able to distinguish that during boiling, its temperature will remain unchanged. If we try to challenge this estimation by presenting children with or helping them to perform an experimental process of boiling and evaporating water while measuring its temperature, it is easy to see the discrepancy between the initial prediction and the result of the experimental activity. Indeed, as children observe the temperature remaining unchanged during the evaporation process, they are led to conclude that their initial estimation was incorrect. This approach to the issue, based on its perceived characteristics, points to a conflicting process: children predict something that is experimentally disproved.

However, despite the fact that children seem to be led to acquire new knowledge through the conflict between the thermometer's observations and their initial predictions, in reality it is difficult to claim that they can reach any level of understanding of the phenomenon. Although the result of the experimental process contradicts their initial prediction, there seems to be no possibility that the children will arrive at a new and adequate interpretative reasoning, as they are unable to explain this result on the basis of even a basic descriptive model of the structure of matter that would allow them to understand the mechanism of phase change. Without planning, preparation, and mental tools that allow students' observations to be integrated into a microscopic model of the phenomenon, children simply record the new data as mere information. However, they are unable to understand the underlying reasoning that during phase changes in materials, the heat supplied or extracted is required to increase or decrease the energy of the building blocks of the material and to understand the consequences of this. The information obtained from observation or the collection of experimental measurements is undoubtedly interesting and destabilizing for students' thinking, but we cannot claim that the whole process constitutes cognitive conflict. In order for this destabilizing process to develop into a real cognitive conflict, it is necessary to be able to process at a microscopic level, i.e., appropriate planning and preparation in curricula and educational design.

2.3. Situation 3: The displacement of an inert body

Often, even in the final years of school, students use a clear intuitive reasoning to assess the kinetic state of bodies, based on the principle that ‘when we apply a force to a body at rest, it is sufficient to set it in motion’. Much could be said about the relationship between this mental representation and the Newtonian model, but it is certainly an assessment that ignores or simply does not include the friction in the movement of the body. To transform this type of mental representation of the transition from rest to motion, we suggest the following experimental activity for children: “On the surface of a table, there is a body at rest. Using a sensitive dynamometer, we apply a horizontal force F to the body, slowly increasing its magnitude” (Figure 1). We ask the children to record the kinematic state of the body in relation to the magnitude of the force exerted. Thus, as long as force F remains less than the static friction T developed between the body and the table, the body remains stationary, while when force F exceeds static friction, the body will begin to move.

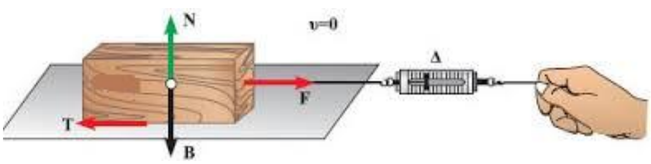

Figure 1

We could assume that this activity leads children to a cognitive conflict, as the experimental process refutes their initial belief about the immediate movement of the body when force F is applied. However, if they have not at least familiarized themselves with the characteristics of a qualitative and semi-quantitative model for the concept of friction, they are obviously unable to compare the two opposing arguments, namely the initial one they formulated, ‘every force is capable of moving the body’, and the one supported by the result of the simple experiment, ‘the kinematic state of the body depends on the net force exerted on it’. This is even though children can think in terms of the second reasoning, since they are familiar with the issues of force and motion as they arise from the Newtonian model. However, since they cannot handle the parameter of friction as a force that opposes the force exerted on the body via the dynamometer, they are unable to arrive at a conclusion that relates the resultant force in the horizontal direction to the change in the kinematic state of the body.

2.4. A comment

Knowing, therefore, that learning processes aimed at creating cognitive conflicts are not automatically effective but are subject to mental processing by children, we must be prepared to accept that their outcome is uncertain. However, despite any reservations aimed at protecting us from the optimism of general prestige and global solutions through conflict, the design of situations of cognitive destabilization and subsequent transformation of students' thinking through real conflictual teaching processes can offer significant benefits to the teaching of Natural Sciences. Nevertheless, a necessary prerequisite for accepting the significance of these conflicting processes is the certainty that the effectiveness and functionality of quasi-cognitive conflicts are not the product of "local" empirical considerations of teachers and/or researchers, but rather a given of systematic study. In this project, it's important to clearly define both opposing arguments. Students must also be able to understand both and recognize them as opposing and mutually exclusive. That is, if one argument is valid, the other cannot be valid.

3. GENRES OF COGNITIVE CONFLICT PROCEDURES

It is well known that during the teaching of Natural Sciences in school classrooms or laboratory exercises, discrepancies in considerations are often observed between teachers and students or even between students themselves. However, as we have seen, such inconsistencies do not necessarily constitute a conflicting teaching process. In order to be able to claim with certainty that a cognitive conflict has been achieved, we must first conduct a systematic analysis and study of exactly which cognitive parameter of children's thinking we want to transform, what specific effects this transformation is expected to have on the students' reasoning, and what ultimately emerges or is likely to emerge in the children's thinking, in the specific circumstances in which the conflict was attempted. Furthermore, it should be emphasized once again that we cannot characterize a teaching process that aims at cognitive conflict as successful when, at the end of it, children have encountered situations from which they simply draw information that contradicts their initial assessments. Unfortunately, in several studies, particularly those oriented towards a broad but epistemologically ambiguous trend in Science Education known as ‘conceptual change’, data that are just based on simple observations of perceived contradictions or experimental refutation of predictions are presented as cognitive conflict.

However, the purpose of teaching Natural Sciences is not to guide students towards certain empirical findings based solely on perception, but rather to build mental representations and/or mental models (Boilevin, 2013; Otero, 2009; Ravanis, 2020). These representations and models allow children to generalize the patterns of assessment, reasoning, and thinking processes they use to approach phenomena first and then the concepts of scientific knowledge in school. Therefore, in order to prepare for cognitive conflict during the teaching of Natural Sciences, it is necessary to:

- We must determine in advance the basic structural and functional elements of the specific teaching subject that constitutes the field of reference.
- Be familiar with the characteristics of students' mental representations.
- Precisely define the objectives of the expected cognitive conflict.

By understanding both the important elements of the subject matter and children's mental representations, we are able to identify the gaps and differences between them and create learning situations that will maximize the possibility of effective cognitive conflicts.

We will then attempt to identify the fundamental theoretical characteristics of different frameworks in which cognitive conflict has been defined as a distinct concept, frameworks that impose conditions and prescribe the objectives and scope of conflictual learning processes. Thus, in the field of psychological research, the utilization of certain results of which is a functional necessity for the teaching of Natural Sciences, three types of cognitive conflict processes can be distinguished (Inhelder, Sinclair & Bovet, 1974), which we will discuss in detail:

1) simple cognitive conflicts,
2) operational conflicts, and
3) socio-cognitive conflicts.

We will also provide relevant examples from each category of cognitive conflict, attempting to highlight their relevance to the teaching of Natural Sciences.

3.1. Simple cognitive conflicts

Simple cognitive conflicts are basic forms of conflict, as they depend almost exclusively on the arrangement and specialized use of objects, materials, instruments, and devices. In other words, when organizing teaching activities, cognitive disruptions often arise based on perceived characteristics of the experimental setups and the corresponding manipulations of the participants. Simple cognitive conflicts arise when contradictions emerge in the perceptual and then in the mental field between children's predictions or assessments and the findings they observe during the course of experimental procedures.

Let us assume that a child, based on his or her mental representations, attempts to predict the outcome of an experimental activity or makes certain predictions when faced with the solution to a problem. If, during the teaching activity, the result of the child's own actions or the corresponding actions carried out during the interaction with the teacher do not confirm the child's initial assessments, it is clear that the contradiction that arises between what was expected and what is ultimately observed inevitably creates a cognitive imbalance or disruption. Under the conditions described by Hewson and Hewson (1984), which we have already discussed, children may construct this cognitive destabilization in their minds as a cognitive conflict. However, when working with students in a teaching context, we try to create the conditions for communication to lead to the valorization of conflicts and the construction of new knowledge.

3.1.1. Situation 4: The rectilinear propagation of light

Here we present the basic characteristics of a process that led to simple cognitive conflict and allowed the transformation of the reasoning of approximately ten-year-old students regarding the rectilinear and omnidirectional propagation of light (Ravanis & Papamichaël, 1995). These students had already explored the concept of light as an entity that propagates from light sources into space (Ravanis, Papamichaël & Koulaidis, 2002), and so the issue of the path of propagation was the next step in a learning sequence of teaching activities. After an initial research phase, during which the children's mental representations were explored, it was found that two cognitive obstacles dominate their reasoning:

1) Firstly, many children do not recognize that light propagates isotropically in all directions. Their thinking often focuses and becomes trapped on various points or directions in space, always in relation to the positions of objects, light sources, and specific characteristics of the experimental materials and devices. The preferred directions in which children often believe light propagates are horizontal and/or vertical.
2) Also, many children do not recognize that light travels in a straight line. They often believe that its path can be bent or even curved when it encounters various objects or when the arrangement of objects in space is such that it traps children's sensory perceptions and leads them to assessments that are incompatible with straight-line propagation.

In an attempt to create conditions for cognitive conflict with the first cognitive obstacle, namely the assumption that light propagates in a certain preferred direction, such as horizontally or vertically, we used a simple setup with a table lamp and a doll (Figure 2) and asked the children to predict ‘whether the doll's face will be illuminated when we turn on the lamp’ by placing the doll in various positions and avoiding the horizontal and vertical axes.

When the children made negative predictions, we asked them to experimentally verify the accuracy of these predictions. After turning on the lamp and seeing that the doll's face was illuminated, we asked them to turn off the lamp, move the doll to different positions, make new predictions, and test them experimentally. Immediately afterwards, we asked the children to explain how they thought the doll's face was lit, given that it was not in a horizontal or vertical position in relation to the lamp. The repeated contradictions between predictions and observations were already having a destabilizing and/or conflicting effect on the children's thinking, so that several of them formulated new ideas based on the idea of light spreading in different directions. During the discussions that followed, we asked them to show us the path that light takes from the lamp to various directions, attempting to guide them toward the ‘materialization’ of the light paths.

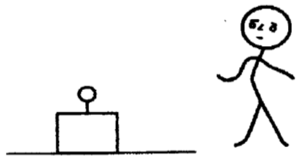

Figure 2

To tackle the second cognitive obstacle, namely the difficulty in recognizing the straight-line propagation of light, and to help the children understand this property, we gave them an opaque straight tube, open at both ends, and asked them to predict and experimentally confirm whether, looking through the tube, the light from the table lamp would “reach their eyes” (Figure 3).

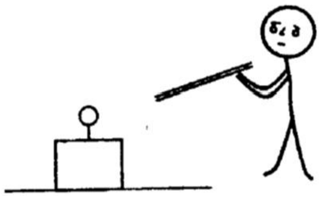

Figure 3

Children usually answer this question in the affirmative, basing their reasoning on the straight-line propagation of light through the tube, and every experiment confirms their predictions.

Immediately afterwards, we gave the children an opaque tube which, at one end, curves significantly so that light cannot pass through. We asked them to predict and experimentally confirm whether, when looking through the tube, the light from the table lamp would “reach their eyes” (Figure 4).

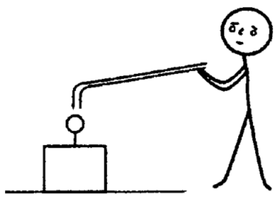

Figure 4

Many children predicted that if they handled the tube properly, they would be able to get the light to reach their eyes. They conducted numerous tests, moving the light source and the tube in various ways, modifying the relative positions of both objects many times, and finally concluded that it was not possible for the light to reach their eyes. When they finally concluded that light cannot pass through this tube, we asked them to explain what they attributed the obstruction of light to, and above all, to describe the path of light rays. The study of the children's reasoning after participating in the experimental process showed that most of those who predicted before the experiment that light would reach our eyes now explained the path of the rays as straight-line propagation and therefore arrived at the opposite conclusion to their initial prediction.

This change in children's reasoning was confirmed in a series of other experimental situations that aimed to extend the study of the issue of understanding the straight-line propagation of light, but also in situations where the aim was to approach phenomena that require the use of straight-line propagation, such as the formation of shadows (Ravanis, Zacharos & Vellopoulou, 2010). The success of the conflict-based teaching process proved to be consistent, as it was tested two and four months after the specific intervention.

3.1.2. Situation 5: Force and motion

It is well known that many children, at all levels of education, approach the relationship between forces exerted on material bodies and the movements they perform on the basis of a series of ‘intuitive principles’ that contradict the principles of the Newtonian model, i.e., the framework from which school knowledge is derived (Gunstone & Watts, 1993). One of the intuitive principles that children use leads to the connection between maintaining the motion of a body and the continuous application of a force (‘constant motion requires constant force’). Obviously, this idea is formed in their minds under the influence of everyday experience and could be attributed primarily to the use of a line of reasoning that does not include, among all the forces acting on the body, the force of friction and its consequences. Based on this information, a teaching activity was designed with the aim of leading children to a cognitive conflict with the intuitive principle ‘constant motion requires constant force’, using experimental setups with the use of synchronized visual aids and/or computer simulations of the experimental setup.

In order to work with children trying to challenge the idea that ‘constant motion requires constant force’, it makes sense to try to minimize or eliminate the role of friction, since this is a factor that significantly influences children's reasoning. Indeed, since friction as an applied force does not fall within the realm of perception, it influences thinking but cannot be the subject of cognitive processing, often even after teaching, and especially with younger children. So, when a body is pushed by a momentary force, it moves for a short time and then stops. The experience of everyday life leads children to think that ‘since no force is being applied, the body stops moving’, thus confirming the initial idea we mentioned.

The development of a teaching activity aimed at leading children to cognitive conflict should allow for the observation of a sustained movement of a body without the continuous application of force. This situation is clearly impossible to achieve in a conventional school laboratory. So, as part of a special teaching activity, it was examined how a disc of solid CO_2 (which solidifies at -78.5 °C) moves on the surface of a glass table, a movement that is maintained long after the initial push, since friction in this system between solid CO_2 and the glass surface is minimal. The device was placed in a transparent cage, and the disk was propelled by air blown from a vacuum pump tube, which passed into the cage through a special hole. In this way, the children could set the disc in motion by blowing on it and watch it move across the glass table at almost a constant speed. After the end of the experimental procedure, the children, using a computer simulation, were able to adjust the amount and direction of the air that set the body in motion, i.e., the magnitude and direction of the force exerted, and to observe and measure the result (Langford & Zollman, 1982).

This special teaching activity allowed the children to recognize the opposing arguments about the relationship between ‘constant force and constant motion’ and to mentally disconnect the constant motion of bodies from the constant forces exerted on them.

3.2. Operational cognitive conflicts

Piaget (1975), studying the destabilizations and cognitive disruptions that can be caused in children's thinking by the conflicts of their own contradictory responses, observed that even if it appears that the child does not pay attention to this incompatibility, they quickly begin to include it in their efforts to formulate new relevant reasoning. These data supported his theoretical explorations into the role of destabilization and reconstruction of mental schemata in the transformation of thought and the achievement of higher-level mental equilibriums, if the concepts of ‘mental schema’, ‘cognitive structure’, and ‘equilibrium’ are used here in the strict sense employed in the tradition of genetic epistemology (Piaget, 1974).

In some attempts to study the conditions under which cognitive development is accelerated, children were engaged in problems that could be approached using contrasting mental schemata. The ‘mental schema’, in the context of the piagetian tradition, is the general structure of an action performed by the mind, i.e., that which remains unchanged when the action is repeated in different circumstances. The mental schemata used are related to the level of a person's cognition and thus, based on their qualitative function, we can distinguish them into schemata of different levels.

Research conducted in this direction has shown that conflicts arise between mental schemata used to deal with problematic situations, conflicts which very often enable children's cognitive progress (Inhelder, Sinclair & Bovet, 1974). Thus, operational conflicts are recognized as those processes during which, in a person's mind, there are confrontations between mental schemata that allow for the formulation of higher or lower levels of reasoning.

The process of creating an operational conflict is stable. Let us assume that a person who is in a period of equilibrium in their mental activity, i.e., at a certain stage of cognitive development, uses a specific mental schema to formulate thoughts related to a cognitive problem that they are called upon to solve. If the reasoning expressed is confronted with another line of reasoning that originates from a different, higher-level mental construct, then the balance of the initial mental activity is likely to be disrupted. Thus, it is possible for the resulting operational conflict to manifest itself (Lefebvre & Pinard, 1972). This process often leads to the disruption of the initial mental schema, the adoption and appropriation of a more advanced mental schema, and ultimately to a new balance of thought at a higher level, which marks not only the successful conflict process but also simultaneous cognitive progress.

3.2.1. Situation 6: The time of light propagation

Here we present an attempt to create an operational cognitive conflict, the aim of which is to understand the propagation of light as a process that evolves in time and space, by students aged around ten years old. The investigation of students' mental representations showed that their estimates of the propagation time of light are made using intuitive mental models in which it is not possible to coordinate variables such as velocity, distance, time duration, along with parameters such as starting point and arrival point. For example, if we ask children to estimate which of the two people in Figure 5 will be reached first by the light if the ‘beacon’ in front of them turns on, the overwhelming majority will choose the person who is at the highest point, as they use an intuitive mental model that does not correlate distances and times, but gives priority to the ‘low-high’ relationship.

Figure 5

Their predictions remain strictly linked to the content and perceptual characteristics of the problem under consideration, with the result that some children believe that light takes time to travel, but only when it covers long distances (Ravanis & Kaliampos, 2018; Ravanis, 2019). In order to contrast the intuitive-prelogical (non-logical) schema with another cognitive schema that transcends intuition and acquires a logical character, on the basis of which a proportionality between the times of propagation and the distances traveled by light will be recognized, we attempted to contrast arguments produced on the basis of the two schemata.

We used a child's doll and a table lamp that was not operating. We placed the doll a long distance from the lamp and asked the children: “If we turn on the lamp, will its light reach the doll immediately or will it take some time?”. In response to this question, due to the great distance involved, children usually intuitively estimate that it will take some time. Immediately afterwards, we move the doll closer to the light source and repeat the question at intermediate positions. As long as the distance remains ‘great’ in the children's minds, always assessing it using an intuitive-prelogical mental schema, they respond that it takes time for light to reach its destination. As we continue to approach the light source, suddenly and intuitively, from a certain position and then apparently ‘close’ to them, the children begin to invoke a mechanism of instantaneous propagation of light. Once we have identified the change in the type of response, we insist on an explanation: “What changed from one position to the other?” and “Why did the light need time in the previous position, but not now?”. This process seems to have created a conflictual situation, as it imposed the replacement of the intuitive ‘far-near’ scheme with a logical scheme of measured distances, and thus brought about a desirable cognitive reconstruction. The mental schema of light propagation based on intuitive estimates without space-time rules was replaced by a schema linking propagation times and distances traveled. Indeed, when these students were later asked to respond to problems that require coordination between time and light propagation distances, they succeed without being influenced by the spatial arrangement of the objects in the problem. Furthermore, this schema shapes and/or consolidates the concept of constant velocity for a propagating entity such as light.

Despite their undeniable educational value in revealing the deep-rooted processes of children's mental development, these types of cognitive conflict procedures are not easily applicable to teaching, as they are oriented towards highly specialized cognitive abilities whose scope cannot be distinguished within the vast range of concepts and phenomena dealt with in the teaching of Natural Sciences.

3.3. Socio-cognitive conflicts

Very often, when children encounter a problem or attempt to answer a question, they direct their thinking toward only certain characteristics of the situation under consideration. Thus, they formulate reasoning which, being dominated by specific elements of experimental situations, does not lead to satisfactory approaches, interpretations, and answers. For example, when a 9-year-old child was asked, after attending some introductory Biology lessons, to draw and explain how embryos feed, he made the following drawing (Figure 6) and approached the problem based on this drawing (Giordan, 1987).

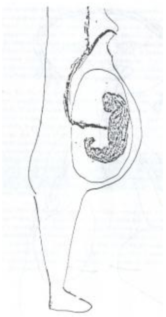

Figure 6

As can be seen, here the required estimation is made using a combination of the individual elements of the problem (fetus, uterus, umbilical cord, mother's breast). These elements are organized based on the perceptual attachment to the mental representation that is constructed in everyday life for the nutrition of the infant. Based on this familiar image, the mental representation of breastfeeding dominates the thoughts of this child.

The cognitive process of forming estimations based on adherence to certain characteristics of a situation is called ‘centration’ in psychological research (Bednarz & Garnier, 1989; Carugati, De Paolis & Mugny, 1981; Mugny, Doise & Perret-Clermont, 1975). Focusing is attributed to the use of reasoning that, as it is not yet integrated into an overall thought structure, is mainly influenced by the powerful and/or intellectually appealing perceptual data of the situation.

In such circumstances, simple cognitive conflict procedures may not be effective, as the empirical content of the experimental activities itself traps children's thinking and prevents them from identifying the conflicting reasonings.

For example, Figure 7 shows an arrangement with which we attempt to study whether 10-11-year-old children are able to make estimations about the straight-line propagation of light (Ravanis & Papamichaël, 1995). The setup consists of a table lamp, a screen A with a hole slightly above the lamp bulb, and a screen B. We ask the children to tell us whether “turning on the lamp will cause light to appear on screen B and, if so, at what point”.

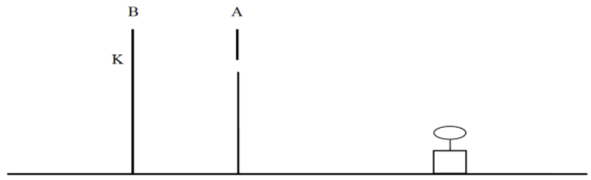

Figure 7

When asked this question, even children who generally recognize that light travels in a straight line and in all directions often get ‘stuck’ and focus their thinking on the hole. As a result, they predict that after moving toward the hole, the light will reach screen B, but at point K, which is directly opposite the hole. Explaining their reasoning, they describe a path of light diagonally from the lamp to the hole and from there horizontally to screen B. For some children, even after their reasoning has been disproved when the lamp works, and even after a discussion about the difference between their initial anticipation and experimental data, the focus on the hole remains strong and the reasoning that recognizes that the light will form a bright spot at point K is repeated unchanged despite some hesitations.

At this point, the influence of the social environment on learning becomes particularly interesting, not in the sense of general social influences, but in the form of systematic teaching intervention, mainly on the part of teachers. As relevant research has shown, creating conditions for interaction with children with the aim of shifting their focus is a source of cognitive progress. Indeed, when, in an attempt to formulate ideas about a given problem, the focus of one person in developing a solution strategy conflicts with the focus of another person using a different strategy, we have a process in which cognitive destabilization and conflicts inevitably arise, primarily due to interaction.

Conflicts of this type have been classified as socio-cognitive conflicts, given that the source of the disequilibrium they cause is both cognitive, since they contribute to transformations in thinking, but at the same time and primarily social, since it stems from the conflicting explanations of those involved in a communication situation (Carugati & Mugny, 1985; Doise & Mugny, 1981; Perret-Clermont, 1986; Perret-Clermont & Nicolet, 2001). Thus, when a child, trying to deal with a problem, becomes trapped in focusing on certain characteristics of the problem, a planned teaching intervention can lead them to other focuses, causing cognitive disruption, balancing and transforming their thinking. If this process is designed in a way that, on the one hand, takes into account the logical ‘equipment’ and mental representations of children for concepts and phenomena of Natural Sciences and, on the other hand, responds to the models on which we teach Natural Sciences, it may contribute to the cognitive construction of knowledge with characteristics consistent with those of school scientific knowledge.

Socio-cognitive conflicts are processes that do not simply refer to the now self-evident acceptance of the beneficial role of the social environment in mobilizing psychological mechanisms for learning but also supports the hypothesis that specially designed social-didactic interaction is itself a source of cognitive development. The theory of socio-cognitive conflict "*...recalls, in principle, the older idea that the intervention of social variables is necessary for cognitive development at certain key moments in ontogenesis. It also proposes (and this is its central position) an explanatory model that assigns these variables a decisive role in the mechanism of cognitive construction. This means that social variables are not considered as external factors that can influence the mobilization of a strict psychological mechanism, of which they are external influences. This explanatory model takes them into account as constituent elements of the mechanism itself*" (Gilly, 1988, pp. 20-21).

This theoretical path inevitably leads to the study of interactions, in which different opinions and opposing estimations come together. However, they do not lead to real cognitive progress unless two conditions are met.

1) The child must be developmentally 'ready' to acquire certain skills.
2) Diversity of opinions needs to be managed not at a relational or emotional level, but at a cognitive level (Zittoun et al., 1997).

Based on this approach, a series of studies were conducted, initially examining methodological issues, which also yielded interesting data. As part of this work, an attempt was made to answer various questions that were key points of this particular theory (Buchs et al., 2008; Doise & Mugny, 1981; Perret-Clermont, 1986).

- In cases where cognitive conflict is caused by the opposing strategies of two children of the same age in solving a problem, should the children be at the same or different stages of cognitive development, based on Piaget's coding for the developmental course of thought?
- When conflict is caused by adult intervention, is it necessary to present a strong model response, or does the intervention itself become a source of destabilization for children's thinking?
- If it is deemed necessary to present a model, how will this model relate to the type of answers given by the child?
- When adults interact with children, there is a risk that children will simply imitate the adults' behavior. How can this risk be identified and assessed? Can imitation activities be a source of cognitive progress?
- What is the effect of the social background of the subjects on the outcome of the conflict provoked?

A series of answers were provided to these varied questions through systematic research procedures and applications. In any case, however, the role and importance of creating conditions for socio-cognitive conflicts for learning was highlighted. This finding has also influenced education, even though very often the core of the relevant efforts lacks a systematic relationship with what socio-cognitive conflicts are and how they are created.

3.3.1. Situation 7: The height energy

After completing the conventional course of study on mechanical energy, students are known to encounter, among other things, difficulties in understanding the concept of potential/height energy. For example, many children do not understand that the measurement of the height energy of a system is done in relation to a zero energy value that we arbitrarily assign to a reference level, which is usually the surface of the earth. They recognize the existence of potential/height energy only in dynamic circumstances, such as when certain materials are removed or fall toward the earth's surface, while they cannot make satisfactory assessments when the problem posed represents a system in which the objects under study remain stationary.

We will now present an attempt at teaching intervention with first-year high school students, who were found to encounter the difficulties mentioned above when studying problems using height energy (Trumper, 1997). The design of this intervention aimed to create conditions of socio-cognitive conflict in which children's thinking is led to recognize contradictory reasoning.

The researcher showed the students a picture containing six different dynamic and static situations involving an object. After the children described these states and were helped when they did not recognize something, to ensure that they understood the experimental situation, they were asked to make estimates related to the height energy of the system and/or the body (Figure 8). The researcher and small groups of students participated in this process. The researcher asked questions that guided the children's focus on certain characteristics of the situations. Both the selection and sequence of situations, as well as the design of the questions and communication, helped the children to come into conflict with their initial mental representations.

Let us look at some dialogues between the students and the researcher, which highlight the importance of exchanges and communication between group members in addressing this socio-cognitive conflict (Trumper, 1997, pp. 14-16).

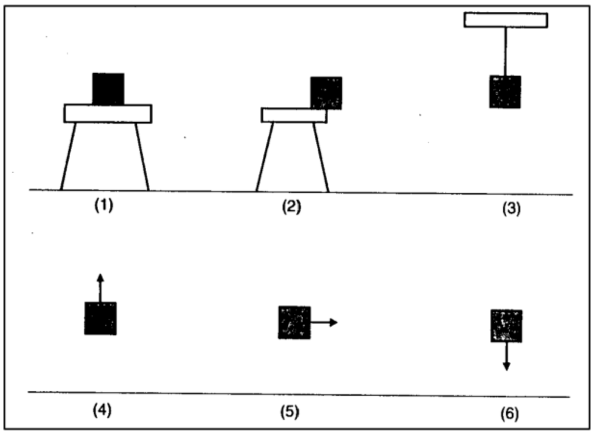

Figure 8

Interviewer: Let's look at situation number 1, a box lying on a table. Has the box height energy?
Liat: I don't know.

Shahar. I say no, because the box could also be on the floor, and this is a place higher than ... let's say the Dead Sea. I think the box has no height energy, because *it stands on a stable place.*
Liat: Maybe it has, because someone lifted it up to the table. Isn't it so?
Hilah: I think there is no energy here, even if the box is lying in a high place. *It is standing on something.* If it would be suspended on air, it will probably have height energy.
Interviewer: Let's look now at situation number 2.
Hilah: Here, I think the box has height energy. It stands partially on air and it can fall. It is not in a stable situation and so ...
Shahar: I also think that now the box has height energy ... Now it is in a special situation related to the floor ... It doesn't stand totally on something. There is a touch of air... In situation 1 the table made a total separation between the box and the floor, now... I would say the box has height energy partially.
Liat: I cannot decide. Maybe the box has height energy because it can fall, and maybe it hasn't because it stands on the table like in situation 1.

Shahar and Hilah do not see any contradiction between their responses to the two situations. Liat sees there is some problem with it, but she chooses to stay in a neutral position.

Interviewer: You have expressed different opinions. Someone has to be right and someone has to be wrong, you will have to decide. Now, let's see situation number 3.
Shahar: I think the box has height energy. As I said before, now it is totally above the floor.
Liat: But the string is holding the box as the table did before!
Interviewer: So?
Liat: I am only saying that if Shahar claims that now the box has height energy, and when it stood on the table he claimed it hasn't, it is like I said before, yes and no at the same time. I don't know.

Now, we can see more clearly that Liat sees there is a conflict between her peers' answers in the different situations, but she still refuses to make up her mind.

Hilah: Here, only a string is holding the box, you can cut it and the box will fall, so it has height energy because it is in a higher place than the floor. But, when it is on the table you have to move the box away, and only then it will fall.
Interviewer: Let's say that for some unknown reason, the table crashes out.
Hilah: In such a case, die box has height energy.
Interviewer. So what happened with your previous answer? You said the box has no height energy in situation 1, when the box stands on the table.
Hilah: I don't know!

Hilah understood, for die first time, that there is a real conflict between her own responses to the different situations. After some confused silent moments, she momentarily drew back to her original thoughts, and then she tried to explain what was wrong with them.

Hilah: There is a greater probability for die box falling when it is held only by a string, than when it stands on the table.
Interviewer: Besides probabilities, is there a basic difference between these situations?
Hilah: No, there is no basic difference between them. The reason I was confused is the air here [in situation 3] between the box and the floor. It seems higher, or something like that.
Interviewer. Let's see situation number 6. What kinds of energy are involved here?
Shahar: The box has height energy.
Interviewer: What else?
Liat: Yes, I think the box has height energy, it is falling and moving.
Interviewer: What happens in situation 5?
Liat: The box is moving to the right, so it has kinetic energy. There is no height energy here.
Hilah: There is! The box has height energy because it is above the floor, and kinetic energy because it is moving.
Shahar: I think that in all these situations, 4, 5 and 6, the box has height energy, when compared with the floor.
Interviewer: And what about situation 1? Also there the box is higher than the floor.
Shahar: No, no! I am talking only about situations 4, 5 and 6. In situation 1 the box stands on the table.
Hilah: There is really no basic difference between all the situations, in all of them there is some kind *of potential* energy.
Liat: If Hilah says so, it should be right.

In these dialogues, children realize during the discussion that there are contradictions in their reasoning, although they adopt different ways of reacting. The third child (Hilah), realizing that the two arguments conflict with each other, abandons his initial argument and adopts an ‘energetic’ argument that allows him to deal with all the proposed situations in a unified manner. The first child (Liat), although recognizing the conflict, avoids resolving it on his own and invokes the answers of the other children, while the second child (Shahar) does not seem to understand that there are two conflicting arguments and remains attached to his initial mental representation.

These findings, as well as other similar findings from research with the same orientation, emphasize that socio-cognitive conflict is a possibility that arises in the context of planned teaching interactions and not a process of certain transformations at the level of thinking.

3.3.2. Situation 7: The direction and conservation of electric current

As part of a series of introductory lessons on electricity for students aged 12-14, two of the topics taught were the direction and conservation of electric current, A simple electrical circuit consisting of an electrical source, two wires, and a light bulb was used to study these topics (Johsua & Dupin, 1988).

The process began with identifying the students' mental representations of these topics. The results of the research revealed a series of representations by the children, which, after being recorded, were presented for discussion in their classrooms. The creation of conditions for socio-cognitive conflict began with this discussion, as the children, without taking direct information from the teachers, exchanged individual or group arguments, disagreed, and supported or abandoned certain lines of reasoning based on mental representations that they gradually recognized as weak, such as, for example, 'monopolar or one-way current', i.e., connecting a lamp and a source with a single cable that connects both poles.

Thus, finally, the students came to support two types of mental representations for the transmission and circulation of electricity:

1) A group of children focuses on the role of the poles of the source and considers that two currents of opposite directions originate from them and are directed towards the lamp. This reasoning is referred to in the literature as the mental representation of 'competitive currents'.

2) A second group focuses on the lamp and considers that the current moves in one direction and is exhausted when it passes through the lamp. Thus, before it 'passes' through the bulb, there is more of it, and after it 'passes' through, there is less. This approach is recognized in the literature as a mental representation of the 'exhaustion of the current'.

Based on these dominant mental representations of children, simple experimental situations were designed in which interactions led children's thinking to socio-cognitive conflict. In a related teaching proposal, as the teachers were well aware of the reasoning expressed by the children based on their concentrations, they suggested that they study two simple electrical circuits.

The first was created from two identical magnetic needles, a light bulb, and an electrical source (Figure 9). However, the teachers had made sure that the study of the magnetic effect of electric current on compasses and magnetic needles had been covered beforehand, as well as the fact that the direction of rotation of the needle is related to the direction of the electric current.

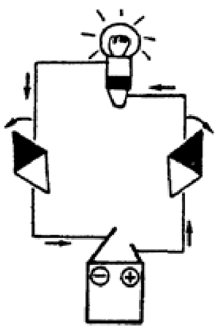

Figure 9

In the second circuit, two amperometers were connected to the positions where the magnetic needles were located before and after the lamp, and the students were also familiar with how they worked.

The teachers asked the children to predict when the current would pass:

- for the first circuit, the response of each magnetic needle and
- for the second circuit, the indications of the two amperometers.

So, the children who made estimations based on their mental representation of the competitive currents believed that the compasses would turn in the same way toward the same direction, since they would be permeated by currents of the same direction. The children who believed that the light bulbs consumed all the current thought that the second ammeter through which the current would pass after the bulb would show a lower indication than the first one. This process creates conditions in the educational environment that provoke socio-cognitive conflicts with children's reasoning. Then, when the two circuits had a current flowing through them, the teachers talked with the kids, figuring out the ideas that came from the results of the experiments and comparing them with their original predictions.

In this process, teaching activities are organized in such a way that the concentrations to which children are systematically led, through a series of actions, conflict with their initial concentrations and actually contribute to the formation of mental representations that allow for reasoning compatible with that of school scientific knowledge. These conflicts, despite being based on the observations made by the students using the measuring instruments, are not simple cognitive conflicts. This is because both the extremely detailed design and the quality and intensity of communication between researchers and children underscore the importance of the social-pedagogical factor in provoking conflicts.

4. COGNITIVE CONFLICT: SOME SPECIFIC REMARKS

Teaching activities that aim to lead to cognitive conflict processes can offer significant opportunities to transform students' mental representations of concepts and phenomena in Natural Sciences. Indeed, cognitive conflicts of all kinds allow children to reorient their thinking, seek new answers to the problems they face, ask new questions, and shift their focus toward characteristics of experimental situations that require them to formulate reasoning compatible with that which is desirable in the context of school knowledge (Waxer & Morton, 2012). These reasonings, which contradict the initial ones they formulate when faced with problems in the field of Natural Sciences, lead students not only to resolve a 'local' contradiction, but also to be sensitive to perspectives that contradict their own. This is a dimension that has broader implications for understanding the nature and character of the Natural Sciences, since in a way it allows for multiple 'readings' of what seems to us to be unambiguous and self-evident.

Of course, the success of processes aimed at cognitive conflicts cannot be guaranteed in advance, as when children are faced with situations that are conflicting for adult thinking, from a cognitive point of view, sometimes they recognize the contradiction and choose the solution that arises from the conflict as the preferred one, while others remain with their initial solution. But even when cognitive conflict functions satisfactorily and this is recorded, it cannot reassure us, because we do not know whether it leads to stable patterns of reasoning that can be generalized or applied to circumstances with similar cognitive characteristics. Based on this finding and given that in the case of teaching and learning Natural Sciences, we are interested in making cognitive conflict an effective learning tool, we must ensure, as far as possible, the conditions and safeguards that will allow us to maximize the chances of sustainable and stable overcoming of cognitive obstacles. In an effort to focus on two important prerequisites, we consider two dimensions related to the breadth and depth of these efforts.

The first relates to the range of potential cognitive conflicts. It is clear that, as cognitive conflicts in science teaching are basically organized around the mental representations, ideas, misconceptions or alternative conceptions of students, the creation of a 'map' of the basic characteristics of mental representations to be addressed and transformed allows us to identify the obstacles to their thinking and organize the conflict processes around them (Driver et al., 1994).

The second dimension focuses on the depth that cognitive conflicts can have. This issue is of particular interest as it directly refers to the added value that can be gained from removing cognitive barriers, which can be achieved through cognitive conflicts. Indeed, since overcoming obstacles is an important condition for the formation of models of scientific knowledge in school, it is clear that the contribution of cognitive conflict is not limited to the transformation of mental representations (Ravanis & Boilevin, 2022).

Thus, these two dimensions highlight the importance of the circumstances in which the knowledge constructed in the students' minds through conflictual processes is applied. Within this context, many different specific issues can be highlighted and studied: the role of logical hypothetico-deductive reasoning (Lawson & Thompson, 1988), field dependence/independence (Witkin et al., 1977), the importance of reactions such as hesitation, surprise, doubt, "internal" dialogue, etc (Cantor, 1983). However, a project with such demands could not fail to be linked to the quality of the learning environment. A key element is well-designed communication during teaching activities, to maximize the chances of a decisive impact on the transition between the two levels of reasoning that children express and valorize in different fields of Natural Sciences (Akpinar, Erol & Aydoğdu, 2009; Bonello, 2019; Kang, Scharmann & Non, 2004; Madu & Orji, 2015; Skoumios & Hatzinikita, 2005). Nevertheless, it is certain that conflictual processes do not function in the same way in systematically controlled research processes and in open educational environments of real school classrooms (Gilly, 1989).

This effort, of course, highlights the importance and priority of socio-cognitive conflicts, which, for the educational process, are probably the main form of cognitive conflicts, since every organized teaching activity is based on interaction. Therefore, from this point of view, it is particularly important to design all educational processes in such a way as to identify topics in which cognitive conflicts can be utilized in the classroom and/or laboratory for teaching Natural Sciences.

5. REFERENCES

Akpinar, E., Erol, D., & Aydoğdu, B. (2009). The role of cognitive conflict in constructivist theory: An implementation aimed at Science teachers. *Procedia - Social and Behavioral Sciences*, *1*(1), 2402-2407. https://doi.org/10.1016/j.sbspro.2009.01.421

Bednarz, N., & Garnier, C. (1989). L'utilisation du conflit socio-cognitif dans une pédagogie contribuant à l'élaboration des processus d'anticipation et décentration. In N. Bednarz & C. Garnier (Eds), *Construction des savoirs: obstacles et conflits* (pp. 334-349). Canada: Agence d'Arc Inc.

Boilevin, J.-M. (2013). *Rénovation de l'enseignement des sciences physiques et formation des enseignants. Regards didactiques*. Bruxelles: De Boeck.

Bonello, C. (2019). Using cognitive conflict to support Maltese student teachers' understanding of abstract science concepts - a case study. In C. Bezzina & S. Caruana (Eds), *Teacher Education matters: transforming lives, transforming schools* (pp. 412-425). University of Malta. Faculty of Education, Malta.

Bovet, M., Parrat-Dayan, S., & Voneche, J. (1988). Processus d'interaction dans la causalité. In A. Giordan & J.-L. Martinand (Éds), *Actes des Xèmes Journées Internationales sur l'Éducation Scientifique* (pp. 299-304). Chamonix.

Buchs, C., Darnon, C., Quiamzade, A., Mugny, G., & Butera, F. (2008). Conflits et apprentissage. Régulation des conflits sociocognitifs et apprentissage. *Revue Française de Pédagogie, 163*, 105-125. https://doi.org/10.4000/rfp.1013

Cantor, G. N. (1983). Conflict, learning, and Piaget: Comments on Zimmerman and Blom's "Toward an empirical test of the role of cognitive conflict in learning". *Developmental Review*, *3*, 39-53.

Carugati, F., & Mugny, G. (1985). La théorie du conflit sociocognitif. In G. Mugny (Éd.), *Psychologie sociale du développement cognitif* (pp. 93-108). Berne: Peter Lang.

Carugati, F., De Paolis,, P., & Mugny, G. (1981). Conflit de centrations et progrès cognitif, III: Régulations cognitives et relationnelles du conflit socio-cognitif. *Bulletin de Psychologie, XXIV*(352), 842-851.

Doise, W., & Mugny, G. (1981). *Le développement social de l'intelligence*. Paris: InterEdition.

Dreyfus, A., Jungwirth, E., & Eliovitch, R. (1990). Applying the "cognitive conflict" strategy for conceptual change. Some implications, difficulties, and problems. *Science Education*, *74*(5), 555-569. https://doi.org/10.1002/sce.3730740506

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making sense of secondary science: Research into children's ideas*. New York: Routledge Falmer.

Flavell, J. H. (1977). *Cognitive Development*. Englewood Cliffs, NJ: Prentice-Hall.

Gilly, M. (1988). Interactions entre pairs et constructions cognitives: Modèles explicatifs. In A. N. Perret-Clermont & M. Nicolet (Éds), *Interagir et connaître* (pp. 19-28). Fribourg: Delval.

Gilly, M. (1989). Construction des savoirs. Obstacles et conflits. À propos de la théorie du conflit socio-cognitif et des mécanismes psycho-sociaux des constructions cognitives : Perspectives actuelles et modèles explicatifs. In

N. Bednarz & C. Garnier (Éds), *Construction des savoirs: obstacles et conflits* (pp. 162-182). Canada: Agence d'Arc Inc.

Giordan, A. (Éd.). (1987). *L'élève et/ou les connaissances scientifiques*. Berne: Peter Lang.

Gunstone, R., & Watts, M. (1985). Children's understanding of force and motion. In R. Driver, E. Guesne & A. Tiberghien (Eds), *Children's ideas in Science* (pp. 85-104). Milton Keynes, UK: Open University Press.

Hewson, P. W., & Hewson, M. G. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. *Instructional Science, 13*(1), 1-13.

Inhelder, B., Sinclair, H., & Bovet, M. (1974). *Apprentissage et structures de la connaissance.* Paris: PUF.

Johsua, S., & Dupin, J-J. (1988). Processus de modélisation en électricité. *Technologies, Idéologies, Pratiques, VII*(2), 155-169.

Kang, S., Scharmann, L. S., & Non, T. (2004). Reexamining the role of cognitive conflict in Science concept learning. *Research in Science Education*, *34*, 71-96.

Karmiloff-Smith, A. (1992). *Beyond modularity: A developmental perspective on cognitive science.* The MIT Press.

Keeley, P., & Tugel. J. (2009). *Uncovering student ideas in science, volume 4: 25 new formative assessment probes*. Arlington, VA: NSTA Press.

Langford, J. M., & Zollman, D. (1982). *Conceptions of dynamics held by elementary and high school students*. Paper presented at the annual meeting of the American Association of Physics Teachers, San Francisco.

Lawson, A. E., & Thompson, L. D. (1988). Formal reasoning ability and misconceptions concerning genetics and natural selection. *Journal of Research in Science Teaching, 25*(9), 733-746.

Lefebvre, M., & Pinard, A. (1972). Apprentissage de la conservation des quantités par une méthode de conflit cognitive. *Revue Canadienne des Sciences du Comportement, 4,* 1-12.

Madu, B. C., & Orji, E. (2015). Effects of cognitive conflict instructional strategy on students' conceptual change in temperature and heat. *Sage Open*, *5*(3). https://doi.org/10.1177/2158244015594662

Mugny, G., Doise, W., & Perret-Clermont, A. N. (1975). Conflit de centrations et progrès cognitif. *Bulletin de Psychologie*, *XXIX*(321), 4-7.

Murray, F. B. (1983). Equilibration as cognitive conflict. *Developmental Review*, *3*, 54-61.

Otero, M. R. (1999). Psicología Cognitiva, representaciones mentales e investigación en Enseñanza de las Ciencias. *Investigações em Ensino de Ciências*, *4*(2), 93-119.

Perret-Clermont, A. N. (1986). *La construction de l'intelligence dans l'interaction sociale.* Berne: Peter Lang.

Perret-Clermont A.-N., & Nicolet M. (Eds) (2001). *Interagir et connaître*. Paris: L'Harmattan.

Piaget, J. (1974). *La psychologie de l'intelligence*. Paris: Armand Colin.

Piaget, J. (1975). *L'équilibration des structures cognitives*. Paris: PUF.

Ravanis, K. (2013). Mental representations and obstacles in 10–11-year-old children's thought concerning the melting and coagulation of solid substances in everyday life. *Preschool and Primary Education, 1*(1), 130-137. https://doi.org/10.12681/ppej.38

Ravanis, K. (2019). Mental representations of light propagation time for 10- and 14-year-old students: didactical perspectives. *Journal of Baltic Science Education*, *18*(2), 276-285.

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. (2018). Mental representations of 14-15 years old students about the light propagation time. *Jurnal Pendidikan Progresif*, *8*(2), 44-52.

Ravanis, K., & Papamichaël, Y. (1995). Procédures didactiques de déstabilisation du système de représentations spontanées des élèves pour la propagation de la lumière. *Didaskalia*, *7*, 43-61.

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.

Ravanis, K. Zacharos, K., & Vellopoulou, A. (2010). The formation of shadows: The case of the position of a light source in relevance to the shadow. *Acta Didactica Napocensia*, *3*(3), 1-6. https://eric.ed.gov/?id=EJ1056131

Skoumios, M. (2009). The effect of socio-cognitive conflict on students' dialogic argumentation about floating and sinking. *International Journal of Environmental & Science Education*, *4*(4), 381-399.

Skoumios, M. (2018). Students' conceptions in Science and socio-cognitive conflict processes. *The International Journal of Science, Mathematics and Technology Learning*, *25*(2), 1-16.

Skoumios, M., & Hatzinikita, V. (2005). The role of cognitive conflict in science concept learning. *The International Journal of Learning*, *12*(7), 185-193.

Smedslund, J. (1966). Les origines sociales de la décentration. In F. Bresson & H. De Montmollin (Éds), *Psychologie et Épistémologie Génétiques*. *Thèmes piagétiens* (pp. 159-167). Paris: Dunod.

Trumper, R. (1997). Applying conceptual conflict strategies in the learning of the energy concept. *Research in Science & Technological Education*, *15*(1), 5-18. https://doi.org/10.1080/0263514970150101

Waxer, M., & Morton, J. B. (2012). Cognitive conflict and learning. In *Encyclopedia of the Sciences of Learning* (pp. 585-587). Springer.

Witkin, H. A., Moore, C. A., Goodenough, D. R., & Cos, P. W. (1977). Field dependent and field independent cognitive styles and their educational implications. *Reviews of Educational Research*, *47*, 1-64.

Zittoun, T., Perret-Clermont, A. N., & Carugati, F. (1997). Note sur la notion de conflit socio-cognitif. *Cahiers de Psychologie*, *33*, 27-30.