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6. ACTIVITY THEORY, HISTORY AND PHILOSOPHY OF SCIENCE, AND ICT TECHNOLOGIES IN SCIENCE TEACHING APPLICATIONS

INTRODUCTION

This paper is part of a study which focused on the restructuring of scientific literacy (Roth & Lee, 2004), in the sense that it proposes a new methodological tool for designing the teaching of scientific concepts to young children. This new approach comes under the umbrella of activity theory. However, if activity theory is employed mainly in the analysis of activities (Engeström, 1987), in the present study it is employed in an attempt to design the activities of students.

In the present study, we apply the expansive cycle which Engeström (1999b) suggests and which he accepts as the acceptable practice of an action, and step by step we are led – through the resolution of contradictions – to the application of new practices. These new practices help us to design activities in the teaching of Science to pupils of primary education. In implementing these we use elements derived from the History of Science and teaching practices which are suggested in the literature and are relevant to their introduction in the teaching of science.

All activities, implemented by the pupils with the help of ICT, do not take place in the traditional environment of a class. Much research on this subject has been undertaken internationally. It shows that the incorporation of elements from the History of Science and the use of ICT in the teaching of science to young pupils stimulate the interest of the children and enhance the understanding of the concepts of science. In this study, following an exposition of activity theory, as propounded by its advocates, we describe the contribution of the elements of history and philosophy of sciences in education, as well as the ways which are suggested for their introduction. Furthermore, the necessity which has arisen at present for the use of new technologies in education is also analysed.

The aim of this study is to offer teachers a new methodological tool for the analysis of the activities of the pupils as well as the planning and designing of such activities with the intention of upgrading the quality of the teaching of science.

As a case study for the design of activities we chose the concept of electromagnetism. We followed the historical development of the idea from ancient times – when electric and magnetic phenomena were clearly distinguished, until their unification by Ørsted and Faraday. For the collection of the data of the research a variety of methodological tools was used (videos, works by other students) and their analysis took place under the main tenets of activity theory.

K. Plakitsi (ed.), Activity Theory in Formal and Informal Science Education, 111–157.

THEORETICAL FRAMEWORK

The Framework of Activity Theory

Cultural-historical psychology, as formulated by scholars representing many national traditions begins from the assumption that there is an intimate connection between the specific environment human beings inhabit and the fundamental, distinguishing qualities of human psychological processes. Activity theory (AT) is a social psychological theory about the development and the dynamics of collective human activity.

Activity theory provides a context of human activity and proposes a set of practices which link individual to social activity (Engeström, 1999a; Nardi, 1996).

The fundamental structural unit of the theory is human activity taking place in the smallest possible context necessary to understand it and includes the subject – which is a person or a group (e.g. a group could consist of a student or a group of pupils or students and teachers) performing an activity on an object – as well as the dynamic relationships which develop among them and the socio-cultural rules governing the activity (Barab et al., 2003; Cole, 1999; Engeström, 1999b; Kaptelinin et al., 1999).

Davydov supports the view that an activity depicts a specific aspect of social coexistence of people and this activity is a deliberate change of physical and social reality (Davydov, 1999). Wolff-Michael Roth (2009) calls for the inclusion of sensuous aspects of work in the unit of analysis. He names emotions, identity, and the ethico-moral dimensions of action, such as salient sensuous aspects. Roth suggests that sensuous aspects may be approached by focusing on actions together with their effects.

Activity theory provides all the necessary tools for a theoretical and methodological approach in the design and analysis of educational activities, which include much more than a tool that mediates between the subject and the objectives of teaching (object) (Barab et al., 2003). As we argued in our earlier paper (Stamoulis & Kokkotas, 2006) it is not sufficient to design a tool for an activity; it must be a tool that will be in the service of social interaction. We should not be designing tools but plans for social participation, especially with the use of computers, where the emphasis is transferred from human-computer interaction to human-human interaction. These tools of improved subject-object interaction involve some core issues, such as agent structure, communication, group awareness, consistency maintenance, and collaborative tasks.

Activity theory has applications in different fields of educational psychology (Koschmann, 1996), in human-computer interactions (Kuutti, 1996; Nardi 1996) and in the design and analysis of educational activities (Barab et al., 1999; Johanssen & Rohrer-Murphy, 1999; Kaptelinin et al., 1999). The model description of each activity is suitable for mapping the observed actions of subjects in ethnographic studies (Barab et al., 2004; Engeström, 1999b; Mwanza, 2000).

Engeström (1999b) suggests that we may distinguish between three theoretical generations in the evolution of cultural-historical activity theory.

> The first generation, centered around Vygotsky, created the idea of mediation. This idea was crystallized in Vygotsky's (1978, p. 40) famous triangular model of 'a complex, mediated act' which is commonly expressed as the triad of subject, object, and mediating artefact. The insertion of cultural artefacts into human actions was revolutionary in that the basic unit of analysis now overcame the split between the Cartesian individual and the untouchable societal structure. The individual could no longer be understood without his or her cultural means; and the society could no longer be understood without the agency of individuals who use and produce artefacts. This meant that objects ceased to be just raw material for the formation of the subject as they were for Piaget. Objects became cultural entities and the object-orientedness of action became the key to understanding human psyche. […] The concept of activity took the paradigm a major step forward in that it turned the focus on complex interrelations between the individual subject and his or her community. […] Ever since Vygotsky's foundational work, the cultural-historical approach has been very much a discourse of vertical development toward 'higher psychological functions.' Luria's (1976) cross-cultural research remained an isolated attempt. Michael Cole (1988; see also Griffin & Cole, 1984) was one of the first to clearly point out the deep-seated insensitivity of second generation activity theory toward cultural diversity. When activity theory went international, questions of diversity and dialogue between different traditions or perspectives became increasingly serious challenges. It is these challenges that the third generation of activity theory must deal with. The third generation of activity theory needs to develop conceptual tools to understand dialogue, multiple perspectives and voices, and networks of interacting activity systems. In this mode of research, the basic model is expanded to include minimally two interacting activity systems.[1]

It should be noted that ten years later Engeström suggests that this theory should be expanded to address the various objections that have been raised against its major tenets and that it should be permitted to find its own. It is in this context that we are suggesting in this work that this theory should be developed in the direction of planning and designing of activities.

Learning, knowledge, and expertise – according to the activity theory – are effectively distributed through the participation of people in the community. This theory questions the notion of authority and specialization residing within an individual as opposed to such notions residing in a wider social context. So a new system for studying the intra-individual activity, the interpersonal level and the wider community is proposed (Engeström, 1999b; Leontiev, 1979).

Learning is considered to be a process of social interaction at micro, medium and macro levels. Co-operating with others, a person develops skills and abilities. Central roles in the process are (a) collaborating and (b) language as a tool which shapes the identity of the individual (Leontiev, 1979; Nardi, 1996; Vygotsky, 1978). Within this framework, the teaching approach is characterised by complex group work and peer tutoring, and the course of development is characterised by increasing levels of awareness, control, and consciousness of higher intellectual functions such as problem solving and reasoning (Wertsch, 1985).

How does the theory of activity support such teaching strategies? What methodology should be followed for planning activities? What actions are necessary to help students internalise the meaning/object of the activity? What is the use of tools? In this study we try to define a framework which may support activity theory for teaching science concepts to primary students. Through the utilisation of data from the History and Philosophy of Science and with the help of computers, we developed a specific application which aims at facilitating the students in the construction and comprehension of the abstract concepts of electromagnetism through an ICT-based instructional package.

According to Engeström the basic concept of activity theory is that learning is a human activity which is socially embedded and mediated by tools. The main idea is that some mental activities such as thinking arise from practical activity, and thus the unit of analysis should include the individual and the social-cultural context in which that activity takes place. The tools mediate the process between subject and object, the rules mediate the processes between the subject and the community, and part of the division of labour mediates the procedures between the community and the object (Figure 1). In other words, tools are used by subjects to achieve an objective, rules are set among the subjects and other members of the community in order to achieve the objective and community members need a division of labour in order to achieve the objective (Engeström, 1987, 1999b, 2001). The objective, in our case, is the construction of an object (e.g., a battery) by the students with the help of computers.

"Object" is a subtle concept: it has material form (i.e., it is a real, material object that is being worked on), but it also embodies the "idea" of the activity, i.e., it has an "ideal" form, that is, the motive, collective purpose, or envisioned outcome of activity (Roth & Lee, 2007). Activity theory is a theory of object-driven activity. Objects are concerns; they are generators and foci of attention, motivation, effort, and meaning. Through their activities, people constantly change and create new objects. Often, the new objects are not intentional products of a single activity but unintended consequences of multiple activities (Engeström, 2009).

Engeström's model shows that the main purpose of an object directed activity in education is the acquisition of knowledge and skills by students. The systemic model of Engeström focuses on three mutual inter-relationships involved in each activity: the relationship between subject and object, the relationship between subject and community, and the relationship between the community and the object (Bottino et al., 1999).

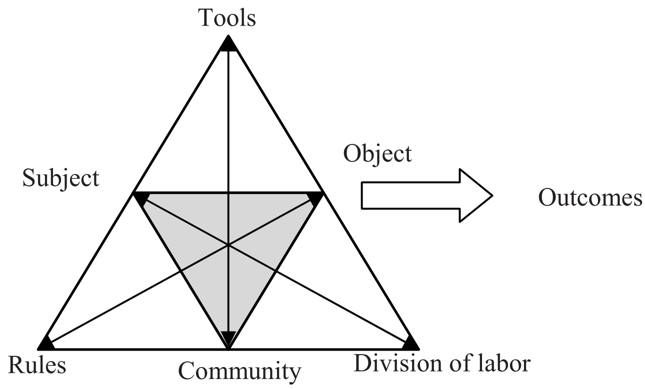

Figure 1. Activity system model (Engeström, 1987).

Mediation is the key to the activity theory. It is the mechanism through which external socio-cultural activities are transformed into internal mental functioning. The source of mediation may be a tool kit (for example, a rope around somebody's hand as a reminder), a system of symbols (language), or behaviour of another human social interaction. Mediators, in the form of objects, symbols, and people transform natural, spontaneous reactions into higher mental processes, as shown in the the diagram above. In the case of science, this intervention may take the form of a handbook, an experimental set-up, a simulation, a material from the history of science or any help from the teacher (Basharina, 2007).

The principle of mediation derives from the work of the Soviet school of Vygotsky, Leontiev, Luria and other works which try to prove the validity of their theory. Mediation activities of the cultural tools (artefacts) and signs are not just psychological concepts, but the key link of the individual with the cultural environment and society.

Vygotsky contemplates the tool of mediation as an auxiliary stimulus which "promotes psychological operation to higher and qualitatively new forms, and allows people, with the help of external stimuli, *to control their behaviour from the outside*. The use of signs then leads people to a specific structure of behaviour that goes beyond organic growth, which creates new forms of culturally mediated psychological processes" (Vygotsky, 1978, p. 78, italics in original).

The idea that people can control their behaviour "from the outside," by creating and using cultural tools of mediation rather than through "internal" factors based on mental functions, could be considered as an optimistic perspective on human self-determination but also as a challenge, a call for study and research on cultural tools as integral components of human functioning (Engeström, 1999b).

Lee and Smagorinsky (2000, p. 3) summarise key aspects of Vygotsky's activity theory as follows:

i. Learning, on an inter-psychological level, often involves mentoring provided by culturally more knowledgeable persons, usually elders, who engage in activity with less experienced or knowledgeable persons in a process known as "scaffolding" (Bruner, 1975). Knowledge is not simply handed down from one to the other, however. Meaning is Knowledge constructed through joint activity rather than being transmitted from teacher to learner.
ii. Concepts or meanings are constructed out of content knowledge, strategies, and technologies, that is, the mediating tools or artefacts that are drawn on in the act of meaning construction – historically and culturally; […] that is, individuals are connected to cultural history and its manifestation in everyday life. People, tools, and cultural constructions of tool use are thus inseparable […].
iii. The capacity to learn is not delimited. Rather, the potential for learning is an ever-shifting range of possibilities dependent on what the cultural novice already knows, the nature of the problem to be solved or the task to be learned, the activity structures in which learning takes place, and the quality of this person's interaction with others. […] Vygotsky (1978) argued that because learning takes place in this zone of proximal development (ZPD), teaching should not extend beyond what a student cannot do without assistance, and not beyond the links to what the student already knows. (Lee & Smagorinsky, 2000, p. 3)

So, the ability of a pupil partaking in the learning process is not delimited. The potential for learning is a continuous process which depends on the dynamics of a society, which is "creating ever new forms of joint activities and the cognitive process takes place both between individuals and within themselves" (Cole & Engeström, 1993, p. 43). On this basis, Marx Wartofsky (1979, in Engeström 1999a), found that cultural mediation tools promote cultural changes, in a way analogous to the role of genes in biological evolution. Activity theory has the conceptual and methodological potential to guide studies which facilitates some control of the cultural tools of humans, and thus of their future.

Wartofsky's work in historical epistemology has exerted a decisive influence on the course of cultural-historical activity theory, as Engeström himself admits (1987). Wartofsky (1979) distinguishes three kinds of artefacts that can function as representations. First are material tools and the social practices in which they are employed; these are primary artefacts in the sense that they are directly involved in the transformation of the environment for the production and reproduction of the means of existence. The first such artefacts were simple tools (knives, spears, and pots); today, they include aircraft, computers, and automatic banking machines. Such artefacts are not created with the purpose of representing, but they can be so used, particularly to represent the activities in which they are typically involved. The second category consists of those that are created with the purpose of preserving the tools and practices by means of which primary activities are organised, and their motives, goals, and knowledgeable skills are passed on to new participants. These secondary artefacts are symbolic representations of the primary activities that are used to plan, manage, and evaluate. Face-to-face mimetic acts would have been the earliest form of secondary artefacts; nowadays they may be in one of a variety of semiotic modes or even in a combination (Wells, 2000).

> Such representations, then, are reflexive embodiments of forms of action or praxis, in the sense that they are symbolic externalizations or objectifications of such modes of action – 'reflections' of them, according to some convention, and therefore understood as images of such forms of action – or, if you like, pictures or models of them. (Wartofsky, 1979, p. 201)

In Wartofsky's classification there is also a third level of artefacts, abstracted from their direct representational function, called tertiary artefacts. Related to the division between "psychological" and "technical" tools made by Vygotsky, language cuts across all three different levels. These tertiary artefacts are the imaginative, integrative representational structures (myths, works of art, as well as theories and models) with which humans attempt to understand the world and their existence in it (Wells, 2000). However, there are interactions, transitions, and transformations between the physical and conceptual dimensions of objects rather than a clear and identifiable separation (Hakkarainen, 2004). With this simple taxonomy of artefacts based on their relation to production Wartofsky offers an alternative approach to this separation.

For Vygotsky, a child's development is above all a matter of becoming a fully functioning (in my terms, autonomous) member of a particular human culture. Social interaction plays a decisive role in this process, providing structures that are gradually internalized as cognitive capacities:

> Any function in the child's cultural development appears twice, or on two planes. First it appears on the social plane, and then on the psychological plane. First it appears between people as an inter-psychological category, and then within the child as an intrapsychological category. […] Social relations or relations among people genetically underlie all higher functions and their relationships. (Vygotsky 1978, p. 104)

How we learn to think, in other words, is determined by the interactive structures in which our early experience is embedded. This argument helps to explain the coexistence in humanity of biological unity and cultural diversity. It also implies that to be optimal all human learning may require a social dimension, and it clearly relates our psychological autonomy to the interdependent processes of social interaction.

Vygotsky also believes that children in their early stages of development perform an activity mediated by a physical or symbolic tool, in co-operation with an adult, to get successful results. The external tool/item needed by children of school age is transformed into an internal point, which is revoked and subsequently used by the person in discussions or in the exercise of other activities. People are involved in many activity systems and, in their own microcosm, the outcomes of their performance are incorporated into the wider cultural context. A person is thus affected by other activity systems in which he or she participates. These influences are horizontal, occurring in small and large communities and perpendicular, incorporating the history, culture and relationships formed in human production activities (Basharina, 2007).

Principles of activity theory. We can distinguish five basic principles of activity theory (Engeström, 2001; Rizzo, 2003) that have been used in recent studies to analyze the success of the mediation of educational materials developed in computer environments and learning situations in which subjects-students with practical cooperative activities are performed to learn. These principles are:

1. The first principle is that a collective, artefact-mediated and object-oriented activity system, seen in its network relations to other activity systems, is taken as the prime unit of analysis (Engeström, 2001, p. 136).

The smallest structural unit of the theory is the activity – a collective system which is mediated by cultural tools and is object-orientated – which is seen in a network of relationships with other activity systems and is the smallest framework for understanding human actions. The activity is treated as the primary unit of analysis. Individual targets, actions of groups, automatic features that can be second-order units of analysis are fully understood only when interpreted within all dimensions of activity.

2. The second principle is the multi-voicedness of activity systems. An activity system is always a community of multiple points of view, traditions, and interests.

A system activity is by definition a multilevel (multi-voiced) formation. It is the orchestrator of different views and approaches of various participants (Engeström, 1999a). The activities are long-term formations whose objects are transformed into results through a process which typically consists of major steps and phases (Jonassen & Roher-Murphy, 1999). The upper level of a "collective activity" is guided to a target/object, the middle level of "actions" of an individual or a group is guided by a conscious purpose, and the last stage of the automatic features is guided by the conditions and tools of the above actions (Engeström, 1987, 1999a).

The activities are carried out as individual and collaborative actions and a series of actions or networks connected to each other via the same overall object and motive. Participation in an activity of this type means making conscious actions that have (and are directed by) a direct and specific target (goal). Every action is first designed by an individual consciousness in a standard way through the use of a mental representation (Engeström et al., 1999; Vygotsky, 1978). For example, an experimental procedure can be represented in Figure 2 (Leontiev, 1978).

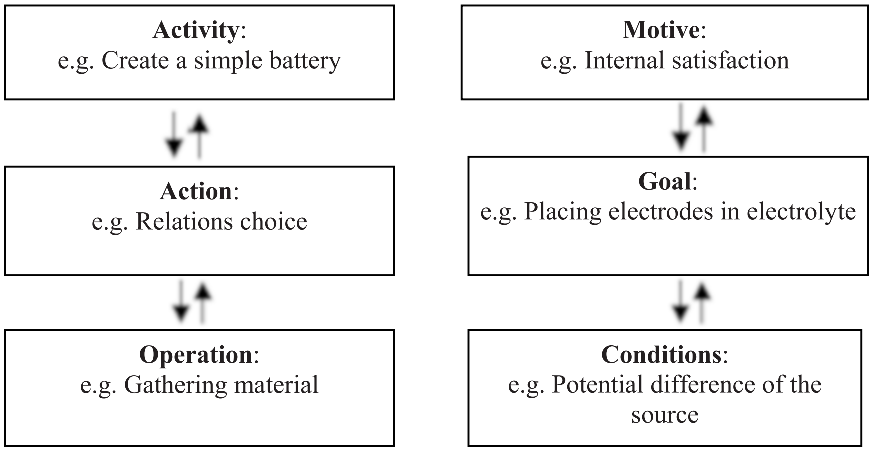

Figure 2. Diagram representation of the hierarchical structure of the experimental procedure.

3. The third principle is historicity.

A key objective of historical analysis is frequency. Longer periods of history have the same characteristics as shorter periods or events, whose analysis gives us new levels of repetitive or cyclical time structures. In this respect, Engeström (1999b) supported and introduced the term expansive cycle.

If we form a bow to depict the repeated cycles or expanse, it is important to note that the time of the activity is qualitatively different from the time of action. The time for action is essentially linear and expects a finite end. The timing of the activity is repetitive and circular.

The expansionary cycle identified two key processes that occur constantly at each level of human activity: internalization and externalization. Internalization is associated with the reproduction of culture; externalization is associated with the creation of new artefacts which make a transformation of the culture possible (Figure 3).

The expansionary cycle of an activity system begins with an almost exclusive emphasis on internalization, socialization, and training students to become capable members of the activity as conducted. Creative externalization occurs first as specific individual innovations. Since the divisions and contradictions of the activity become more demanding, internalization increasingly takes the form of critical mass, and externalization seeks only strategic solutions. Externalization reaches its peak when a new model is designed for the activity and it is applied. When the new model is stabilized, the internalization of innate instruments is still the dominant form of learning and development.

Figure 3. The expansive cycle (Engeström 1999a, p. 34).

These two processes are inextricably interwoven. "It's no longer true to say that people create this [society]. Probably we should mention that people reproduce and transform" (Engeström & Miettinen, 1999, p. 10). A historical perspective would include previous cycles of the activity system.

4. The fourth principle is the central role of contradictions as sources of change and development.

The idea of internal contradictions as the driving force of change and development in activity systems is gaining ground as a basic principle of empirical research (Engeström, 1987). These activities are not isolated units; they are affected by other activities. The external influence could change some elements of activities causing contradictions (problems, ruptures, interruptions). Activity theory uses the term "contradictions" to denote the non-adjustment of data between each of the different activities, or between different development phases of a single activity (Kutti, 1996). In activity theory, contradictions are considered as a source of growth (Bottino et al., 1999) and are the driving force of change (Basharina, 2007).

The same objective is achieved in different ways using the same tools available in different sociocultural contexts. When people from different cultural areas are involved in the exercise of an activity to achieve a goal, the use of tools can interpret a heterogeneous set of communicative practices with different rules. However, the division of labour is not the same, but differs in both the communication style and the personal style of the participants (Thorne, 2003, p. 41). For example, communication tools, Internet/cultural tools are different objects for different communities, leading to diversification effects, communication processes, building relationships, and language development.

5. The fifth principle proclaims the possibility of expansive transformations in activity systems. Activity systems move through relatively long cycles of qualitative transformations.

Engeström (1999b), by defining the concept of "expansive cycle," begins with the accepted practice of an action or activity and leads us gradually into a collective movement or state. This movement is achieved through specific and targeted actions. All actions undertaken in this way form an expansive cycle during which tensions created in a system of activities are dealt with successfully.

This approach is similar to the approach of the theory of networks (Latour, 1988; Bigum, 2000), in which learning is a heterogeneous network between people. Engeström (2001) stresses that there is an interactive approach between activity theory and the theory of networks, but the main tenet (in the theory of networks) leads to the degradation of people with no identifiable internal systemic properties and without contradictions. Activity theory differs from the theory of networks, as it provides a comprehensive instructional framework based on learning and professional development of people when it takes place in a structured environment, such as the "school," and is mediated by new technologies.

This is particularly important because new technologies have been introduced so far in an organized learning environment of the school based on traditional teaching practices. This has led, at best, to a marginal effect by new technologies in everyday workplace learning in the classroom. The fundamental assumption of this approach is based on the pattern of transmission of knowledge from teacher to student. Knowledge and skills are treated as a finite and well-specified object that can be handled well by a "teacher" (be it human or computer) and totally disconnected from any social and cultural context in which the underlying act exists. It introduced the activity theory and expansive learning is what violates the model described above (Engeström, 2001). Teachers and the organized learning system of schools meet the challenge posed by new technologies, and all learn something that is stable and clearly defined but may change gradually over time. In other words, as teachers, during our participation in the implementation of activities, we must learn new forms of activity not previously shown. They are learned as they occur. There is no "competent" teacher who has knowledge.

> A full cycle of expansive transformation may be understood as a collective journey through the zone of proximal development of the activity: It is the distance between the present everyday actions of the individuals and the historically new form of the societal activity that can be collectively generated as a solution to the double bind potentially embedded in the everyday actions. (Engeström, 1987, p. 174)

A typical sequence of learning activities in an expansive cycle is described by Engeström (1999b, p. 383) as follows:

Questioning – criticism or rejection of some aspects of accepted practice and existing knowledge.

Analyzing the situation – The analysis includes the symbolic and practical transformation of the state of affairs to discover the causes or illustrative mechanisms. The analysis relies on questions like "why" (explanatory). One type of analysis is "historical-genetic" and seeks to explain the situation in view of the origin and evolution. Another type of analysis is "real-empirical" and seeks to explain the situation to build a picture of internal relations.

Modelling – Formation of a newly explanatory relationship in a receptive and easily understandable model. This means an explicit, simplified model of a new idea that explains and offers a solution to the problematic situation.

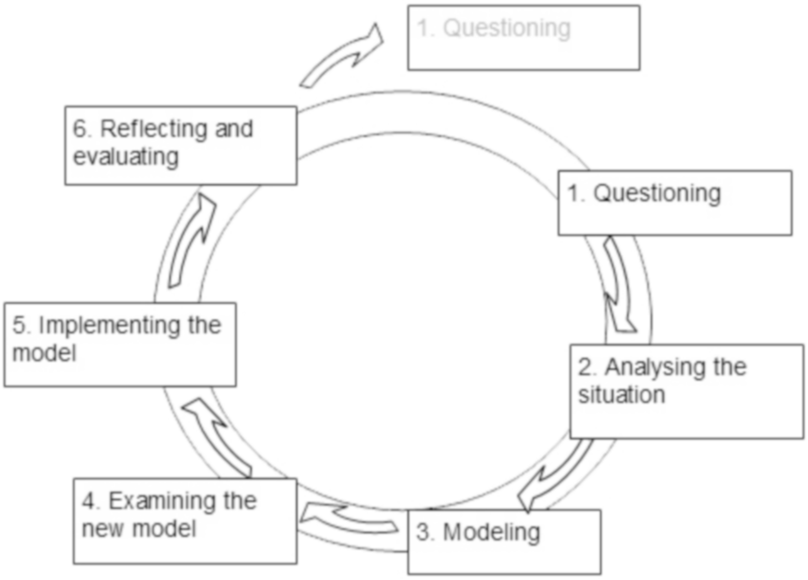

Figure 4. Sequence of epistemic actions in an expansive learning cycle (Engeström 1999b, p. 384).

Examining the new model – implementation, operation, and experimentation with this model so that its dynamic capabilities and limitations can be brought out.

Implementing the model – implementation of the model through practical applications, enrichment, and conceptual extensions.

Reflecting and evaluating – process evaluation and final acceptance in a new, stable form of practice.

The extension of activity theory and the development of expansive learning by Engeström offer a crystal clear view and a new methodology for organised learning in an effort to develop and organise new teaching practices. This perspective is most needed now, as the development of a new methodology of teaching should be able to fully exploit the potential and benefits of new technologies, not only in the classroom but in workplaces where there is no clear pattern. The pedagogical issues are important for promoting innovation with new practices that do not resemble the past (Rizzo, 2003).

In his five principles of activity theory, Engeström considers four basic questions that determine theoretical knowledge and the outcome of any course of learning.

1. What are the subjects of the learning process and how were they selected and defined?
2. Why do they learn? What makes them endeavor?
3. What do they learn? What is the content and outcome of learning?
4. How do they learn? What are the key actions or procedures?

Table 1. Matrix for the analysis of expansive learning basic questions (Engeström, 2001, p. 138).

	Activity system as a unit of analysis	*Multi voicedness*	*Histori-city*	*Contradictions*	*Expansive cycles*
Who is learning?					
Why do they learn?					
What do they learn?					
How do they learn?					

Engeström proposes the use of such an analysis for organized learning environments based on the motivation of individuals to develop various strategies which cause internal tensions and contradictions that form a momentum that will enable people to trigger a serious effort to achieve the objectives of learning (Rizzo, 2003). For the concept of expansive cycle, Engeström begins with individual concerns that question the accepted practice until now and gradually expands into a collective movement from the abstract to the concrete through specific procedures.

In the design of teaching materials for students in sixth grade of primary school, as described above, using Cultural-Historical Activity Theory, we incorporated data from the History and Philosophy of Science. The next section describes the key stages that scientists in the History and Philosophy of Science went through in order to achieve the integration of magnetic and electrical phenomena and the formulation of the theory of electromagnetism during the 19th century. These stages are the backbone of electromagnetism as taught in elementary school.

The History and Philosophy of Science and its Relationship with the Teaching of Science

It was the Greek philosopher Thales of Miletus (~624–547 BC), who circa 600 BC first made a written reference to the phenomenon of magnetism. From the times of

Thales and till the 16th C. electrostatic and magnetic phenomena were unified in the context of a "magic" idea and were supposed to be of the same nature. Their differences were pointed out during 16th C. by Gardano and Gilbert, and two fields of science were established: electrostatics and magnetism. From the 17th C. and up to 1830, scientists dealt with the question of whether electricity derived from different sources was of the same nature. During 1832–1833, Faraday successfully carried out a number of experiments to compare the ability of various electricity sources to produce the same effects (Seroglou & Koumaras, 2001).

The vitalist-animist model and the model of Gilbert are the first attempts to interpret magnetic and electrical phenomena, which are displayed macroscopically and characterized by (Guisasola et al., 2005):

1. The step from the unification of forces to their separation, that is, from the lack of distinction between the gravitational, electric, and magnetic forces to their differentiation into separate forces;
2. The step from a methodology of investigation which was not experimental or qualitative to one based on empirical evidence but not quantified (without a mathematical model);
3. A first attempt to collect data from experimental data.

Vitalist – Animist Model

I. From the ancient Greek philosophers until 1600.

Ancient Greeks were historically the first to attempt a systematic collection of knowledge based on human reason, without limitations and prejudices. So Greek civilization left behind it the basis of a rational philosophy and so the origins of modern western science.

Some ancient Greek philosophers (Thales,[2] Plato,[3] Aristotle), in trying to explain the attraction of magnets and especially magnetite and electrum, gave different interpretations, but their interpretations had a common denominator, which attributed feeling to animate or inanimate matter. The model that had prevailed up to 1600 implied the existence of a hidden force which was embedded in iron and activated by the presence of a magnet or it was moved from magnet to iron. This hidden power is a feature of both amber and magnets and causes the tendency of iron and small objects to move towards the magnet or amber. In ancient and medieval times no distinction was made between gravity and electrical and magnetic forces (Guisasola et al., 2005). A second model by philosophers who believed that the magnetic force is due to some kind of "flow" that is emitted only from the magnet, or even by iron, was not accepted as widely as the Aristotelian view (Voutsina & Ravanis, 2007).

II. Gilbert's model (1600)

In an era of rising humanism and the Renaissance (15th and 16th centuries) a very important new understanding of nature was born. Access to nature was now sought through experiment – a special, modern concept that was first

> shown clearly in Leonardo da Vinci (1452–1519). Experimenting meant setting questions to nature in relation to a prior theory formulated to examine whether the theory is confirmed or rejected by experiment. (Heisenberg, 1997, p. 190)

Gilbert was one of the first to implement this new attitude in the examination of magnetic and electrostatic phenomena.

Modern science and technology largely determines our present attitude towards nature, which is in contrast to that applied in previous centuries, during which natural philosophy expressed an anthropocentric view.

"Any knowledge which does not depend on external causes but only on itself is, for Aristotle and the Aristotelian tradition, knowledge through which the essence of man is realized" (Rossi, 2004, p. 49). This view, that knowledge is devoted to the search for truth, prevailed in ancient and medieval times and led to the belief that mechanical arts, manual work and, by extension, experimentation were lower forms of knowledge. In combination with the theocratic conception of nature, which is presented as a divine creation, any inquiry about the nature of the material world seemed absurd.

The rejection of these frameworks, although launched in the Middle Ages through individual efforts such as those of I. Filoponos, had no effect until the early 17th C., when the whole edifice of the Aristotelian tradition was brought into question. So by the early 18th century, the attitude toward human nature had changed radically. Delving into the details of physical processes, the researcher realized that it was possible to identify individual physical phenomena, a mathematical description, and a resulting "explanation" (Heisenberg, 1997, p. 13). This is the period of amateur science (1600–1800) (Butterfield, 1994). Unlike today, science was not pursued in universities, government, and industry. The participants were men who practised a profession, they were financially independent, and their main social role was associated with something beyond their interest in science (Woolgar, 2003, p. 40)

William Gilbert was Queen Elizabeth's doctor, but his contacts and discussions with sailors led him to deal with magnetic phenomena, as reflected in his treatise "De Magnete, Magneticisque Corporibus et de Magno Magnete Tellure; Physiologia Nova, Plurimis et Argumentis, et Experimentis Demonstrata (About the Magnet, the Magnetic Bodies and the Earth, the Mega Magnet – New Physiology Proven by Many Arguments and Experiments). It is very difficult to answer the question whether this is the last work of natural magic during the Renaissance or one of the first modern scientific works (Rossi 2004). Gilbert experimented but not in a systematic order: the only consistency present was his willingness to try anything that could be done with a magnet (Butterfield, 1994, p. 101).

Gilbert's model is characterized by a change in the methodology used in previous years. It is based on the results of empirical evidence, as opposed to the qualitative focus of previous centuries. Nevertheless, magnetism is understood as a characteristic feature of the objects, such as mass, volume, etc. Both earth and magnets have an intrinsic magnetism. Gilbert not only experimented with magnets, but suggested that the strength of magnetic attraction is the real cause of gravity and that it explains why the various parts of the world remain united (Butterfield, 1994; Rossi

2004). Gilbert's views on gravity took their place among the most prevalent ideas of the 17th century.

Nevertheless, his views were not accepted by scientists such as Kepler, Bacon, and Boyle. Eventually Galileo seemed willing to adopt the more general theories of Gilbert, but he accepted that he did not understand magnetism or its role in the workings of the universe and regretted that Gilbert was so limited as an experimenter and that he failed to express magnetic phenomena in mathematical terms (Butterfield, 1994, p. 143).

In contrast to Aristotle's experiments, which were based on experience, Galileo's experiments were based on an ideal world whose reality is but an imperfect realization. Galileo thought of experiments primarily as ideas with which to persuade others, and he was ready to announce his results with absolute certainty without being bothered to perform experiments (Westfall, 2006).

One of Gilbert's important innovations is the clear distinction he made between magnetic and electric action. He also introduced the term electric power, a term which will attain in the future a unique success (Binnie, 2001; Kipnis, 2005; Rossi, 2004). Electricity, a term that does not appear in his writings, is presented as an attraction that all small and lightweight items undergo (e.g., amber, jet, glass, resin, and sulphur) when rubbed (Rossi, 2004, p. 353). He made the versorium, which was a real electroscope.

Behind the elaborate and intelligent experiments of Gilbert lies a "magical-vitalist" perspective in which matter is not devoid of life or perceptual skills (Rossi, 2004, p. 353). The force of attraction exerted is always proportional to the quantity or mass of the body exerting the force: the greater the mass of magnetite, the greater the "pull" exerted by it on objects. This force is not exerted from a distance but by effluvia materiali – a visible action creates invisible fumes (Butterfield, 1994; Rossi, 2004).

III. The Fluid Model

The second main qualitative leap was from the vitalist to the corpuscular physical theory (from the 17th to the 18th century), characterized by Guisasola et al. (2005) and Kipnis (2005):

a) a step from the vitalist vision to the corpuscular. That is, magnetism is not considered anymore as an innate quality of some materials but as an invisible and unique fluid. Later on, the fluid model is abandoned and magnetism is defined by means of its effects and its operative definitions, finally making a clearly positivist interpretation;
b) a step from a qualitative to a quantitative methodology in which, despite its quantificational aspects, physical magnitudes are not expressed in mathematical terms.

a. The Single Fluid Model Of Aepinus (1724–1802)

As in Gilbert's case, this model was intermediate between the "single fluid" (the prevailing standard for the interpretation of electrostatic activity), which explained magnetic activity, and the model of "action from … distance," or Newtonian model (which started to become the scientific paradigm of the time) which undertook the interpretation of magnetic and electrostatic activity thereafter (Heilbron, 1979).

In the 18th century, the prevailing model was of one or two types of magnetic fluid. The main representative of the model for one type of magnetic fluid is that of Aepinus, who found that the magnetic poles are areas where there is a surplus or deficit of magnetic fluid. He offered an account of the constancy of the magnets and believed that the magnetic fluid is firmly connected to the pores of the material from which it emanates. He assumed that the magnetic fluid particles repel one another and attract particles of iron (Whittaker, 1910). Representatives of the model positing two types of magnetic fluids are Brugmans and Wilcke, who gave them the names north and south; Coulomb found that unlike electric, magnetic fluids cannot be separated, since the two magnetic poles cannot be isolated (Whittaker, 1910).

b. The Newtonian Model of Coulomb (1736–1806)

This model, though clearly inspired by Newton, interpreted the nature of magnetism by positing the existence of two fluids and thus claimed to explain why there are no monopoles (bodies with only one magnetic pole). The main contribution of Coulomb, in the study of magnetism, was the development of a mathematical model which purported to explain the law of magnetic force. He introduced a quantitative method, similar to that used by Newtonian mechanics, and defined its functionality through dynamic effects and the concepts of the magnetic pole and magnetic force (Heilbron, 1979). In this way, the theory of Coulomb applied Newtonian mechanical formulas to magnetism.

IV. The "Big Leap Forward:" The Appearance of Electromagnetism in the 19th Century (Øersted).

A new area opened in 1820, with an impressive statement by Hans Christian Øersted that electricity diverts a magnetic needle, which was originally oriented parallel to an electric cable. Already in the 18th century, it was suspected that there is a link between electricity and magnetism and several experiments were made towards this direction. Now, in the early 19th century, Øersted's experiment verified this link, as testified to by the magnetic effects of electricity, and paved the way for the emergence of electromagnetism. The culmination of his experiments was the breakthrough of 1820: just as a magnet, electricity had the same influence on a magnetic needle, and thus electromagnetism was born.

Øersted's experiments showed the existence of the "power cycle," i.e., of a torque that causes the magnetic needle to rotate. This movement was unexplained by the Newtonian view. Øersted's article was mainly qualitative but created an opening for the study of electromagnetism (Segrè, 2001). Soon after, in the autumn of 1821, came the discovery by Ampère of attraction or repulsion between two pipes through which electricity is passing. The discoveries of Øersted and Ampère contributed to the correlation between magnetic phenomena and electricity (Seroglou et al., 1998).

In attempting to bring electromagnetic forces into the province of Newtonian mechanics, Ampère and others constructed a mathematical representation of them as actions at a distance. Continuous-action phenomena, such as fluid flow, heat, and elasticity, had all recently been given dynamic analyses consistent with Newtonian mechanics. The initial presumption behind these analyses was that, at the micro-level, there are forces underlying action-at-a-distance in a medium and it is these forces which are responsible for the macro-level phenomena (Nersessian, 2002).

The discoveries of Ampère and other researchers in the early days of electricity were expressed in pure mathematical language, so they were representing the ultimate development of Newtonian physics based on the laws of forces between two current elements, or two point loads on the move (Segrè, 2001).

The main model for the study of magnetism in France and Germany in the 19th century was Newton's model of action at a distance. Main representatives are Ampère and Weber. Ampère believed that magnets are created by tiny circular molecular currents which come about through the interaction between currents and magnets; magnetism is simply an interaction between currents (Guisasola et al., 2005).

Scientists of continental Europe followed the trail of Coulomb and Ampère in expressing electromagnetic forces in a differential typology. "They presented the results of the attraction of repulsion and induction as remote interaction of different particles motivated by the Newtonian law of gravity and the expansion of the inverse square relationship to the electromagnetic forces" (Gillispie, 1994).

V. The Field Model

After the discovery of Øersted about electromagnetism, and the arrival of field theory of Faraday, two ontological views coexisted in the scientific community in the 19th century: "action at a distance" and "field theory." They didn't run in parallel, but were often isolated from one another and they formed the basis for all subsequent theories that have arisen.

a. The Field Model of Michael Faraday (1791–1867)

Scientists in England followed a different path. Faraday was the first to demonstrate the reciprocal relationship between electricity and magnetism. After following a series of experiments that created electricity by moving magnets, he offered the idea of a dynamic line, which he actually envisaged as being real in the physical condition of space and defined the concept of power as a key entity in space. In this way, he is the precursor of field theory (Gillispie, 1994).

Faraday had made the hypothesis that the lines of force which are formed when iron filings are sprinkled around magnets and charged matter indicate that some real physical process is going on in the space surrounding these objects and that this process is part of the transmission of the actions (Faraday 1835–55). In 1830, Faraday successfully carried out several experiments to settle the matter and concluded this long scientific argument. (Seroglou et al., 1998). Faraday was convinced that the relationship between electricity and magnetism had to be extended, and if the current created a magnetic field, then the magnetic field should be able to create electricity. He had grasped the essential point that, to produce current, a pipeline had to interrupt the lines of magnetic forces (Segrè, 2001).

b. The Field Model of W. Thomson (1824–1907) and J. C. Maxwell (1831–1879).

This model was introduced for the first time by Thomson and then by J. C. Maxwell, who relied on the existence of ether and engineering to express mathematically the concepts of Faraday and make them more understandable. William Thomson introduced a method of investigation known as "the method of analogies," understood as the following: "the mathematical analogy between fluid of liquid, heat and electricity and magnetism implied a mathematical similarity not a physical one …"; the similarity occurs between the mathematical explanation of this phenomena, not between the phenomena themselves (Nersessian, 1995, 2009).

Table 2. Scientist-scientific model and activity

Greek ancient philosophers	Vitalist–Animist Model	1. From toys with magnets in magnetic phenomena
William Gilbert (1544–1603)		2. From the attraction of magnets to the attraction of other bodies
Franz Aepinus (1724–1802) Charles-Augustin de Coulomb (1736–1806) Charles du Fay (1698–1739) Benjamin Franklin (1706–1790) Alessandro Volta (1745–1827) Luigi Galvani (1737–1798)	The Fluid Model	3. From animals' electricity to batteries' construction
Hans Christian Öersted (1777–1851) André-Marie Ampère (1775–1836)	The "Big Leap Forward:" The appearance of electromagnetism in the 19th century (Øersted).	4. The new discoveries that changed our world: From electricity to magnetism: Øersted's experiment 5. The new discoveries that changed our world: electromagnetism.
Michael Faraday (1791–1867) W. Thomson (1824–1907) J. C. Maxwell (1831–1879)	The Field Model	6. The new discoveries that changed our world: Faraday's experiments that led to electric motors.
		7. The new discoveries that changed our world: Faraday's experiments that led to electric generators.

Maxwell, on the other hand, connects Faraday's ideas to the mathematical analogies of Thomson. Basically, Maxwell's objective was to discover an appropriate model which could explain the basic mechanism of electromagnetic phenomena. He chose Thomson's vortex model. This model allowed him to work out a group of laws which explained all the magnetic phenomena (at a macroscopic level) in a formal way, as well as optical physics. Later he abandoned the mechanical model because it created too many difficulties, and he was left with his equations (what scientific historians call the "The Operative Interpretation"). Hertz's discovery of the waves which are called after his name was the experimental confirmation of Faraday and Maxwell's field theory (Guisasola et al., 2005). Maxwell expressed in mathematics the field concept of electromagnetic forces, formulated the laws of a non-Newtonian dynamic system for the first time, and constructed this novel representation by abstracting and integrating constraints from what was known of continuum mechanics and machine domains and from the new domain of electromagnetism into a series of models and formulated the quantitative relationships among the entities and processes in these models (Nersessian, 2005).

Using the stages of the development of scientific thought on electromagnetism, we constructed corresponding activities to be taught in primary education as shown in Table 2. These activities follow the structure of an expansive cycle and are presented through a computer. Each step of the expansive cycle is a "screen" in which students can work to complete the activity. To be presented effectively and to draw the interest of the students to the data from the History and Philosophy of Science, we use different teaching strategies as described in the literature; they are presented in Chapter 7.

Teaching Strategies Using Data from the History and Philosophy of Science

Various proposals concerning the contribution of the history of science to science teaching were drafted in the early 21st century (Seroglou and Koumaras, 2001). However, integration of elements of the history of science into science teaching seems to acquire a different meaning which is related to the kind of transformation scientific knowledge undergoes when it becomes a school subject (school knowledge).

According to Monk and Osborne (1997), the role of epistemology is crucial to the incorporation of History of Science because the answer to the question of "how we know" is an important aspect of our account of science and provides evidence for our ontological commitments. Furthermore, in the context of science education, scientific epistemology is a central concept – that is, "to tell how to distinguish between justified and unjustified beliefs" is an essential critical skill required for participation in any scientific discourse. For Monk and Osborne, the introduction of the History of Science "will continue to remain more talked about than taught as long as the materials that teachers are provided with have an additional character focusing on the context of discovery, rather than the dominant perspective of mainstream science teaching the concerns of which are in accordance with the products of epistemological justification and the methodology of science (Monk & Osborne, 1997).

Matthews (1994, 1998), along with Stinner and Williams (1998), support the view that the history and philosophy of science should be in the curriculum and proposes that it should:

- be within the context of students' lives, create incentives, inform, and be relevant to the interests of students.
- incorporate the view that the historical context helps students understand that scientific knowledge is not permanent.
- give a human dimension to science and link students with the personal, moral, cultural, and political interests of the people.
- create direct experience for the students who grow up in an environment where information is provided electronically by new technologies, which bring great benefits but also great risks.

To the above we could also add the help which is provided to the students, so that they themselves can: (a) evaluate the landmarks in the evolution of ideas and technologies, and (b) discern what is the important information within the plethora of information available due to the growth of electronic information and especially the Internet.

The main benefit of learning the History of Science consists in the active participation of students. Seroglou and Koumaras (2001) argue that teaching material, which has been designed to facilitate the study of the work of the scientists who helped change scientific ideas and led to the scientific theory acceptable today, could include activities designed and inspired by:

1. Historical experiments with highly visible features that helped change scientific ideas in the history of physics.
2. Abstract reasoning which helped change scientific ideas in the history of physics.
3. A combination of experiments and thoughts that helped change scientific ideas in history.

The transition of thought from the world of senses to a higher level, where the main role is played by concepts, is essential to carrying out activities in the teaching process within the classroom.

Within such a context, data from the History of Science can be introduced in the following forms (Stinner et al., 2003):

1. Story Line We create a story line (perhaps historical or conceptual) that will be activated and will emerge through this central idea/concept. Identifying an important event linked to a person or persons and finding opposing couples or conflicting characters or events that may be suitable for inclusion in history (Stinner et al., 2003). In the development of a scientific concept, scientists sometimes reject the ideas of earlier scientists and develop new ones. Sometimes scientists interpret events differently and extend or modify previous theories. This scientific process continues as concepts develop throughout the course of history.

The stages in the development of scientific knowledge can be constructed – throughout the course of history – as a story line. Stinner and Williams (1998) confirm that the substance of discussions among scientists could help teachers to participate in similar discussions with their students.

Stinner and colleagues (Stinner & Williams, 1993; Stinner et al., 2003) suggest using the story line approach in order to attract student attention and engage their imagination. In the development of a scientific concept, scientists sometimes reject the ideas of previous scientists and develop new ones. Sometimes scientists interpret phenomena differently and extend or modify previous theories. This scientific process goes on as concepts develop throughout history. Stages in the development of scientific knowledge throughout history can be constructed as a story line. Stinner (1995) emphasizes the importance of the grade level of students in the use of a story line for science education. In the elementary school, science stories should be based on student imagination, in middle school science stories they should be based on history, and in high school years popular science literature related to the content should be used to create a teaching context. Stories of science should be developed for students in the early years and middle years.[4]

These story lines may also include the major historical events which occurred during the life of those scientists and influential thinkers of the era, in different fields such as philosophy, social sciences, politics, and literature. It is sufficient if we spent only a few minutes on any different scientific approach followed by other scientists. This creates a connection with the scientists we are interested in, who are the best of their era so that the students may create the right connections. In the context of a story line, any and all following strategies can be used for teaching science.

2. Case study. A case study is a smaller part of a large context of a central idea/ concept and is designed by a team of three students called to present the case study to a group, or rather to the audience of the class (Allchin, 1997; Irwin, 2000; Stinner et al., 2003; Bevilaqua and Giannetto, 1998). Each student undertakes to present one of the following sections:

1. *Historical context:* Present scientific ideas of the particular historical period and show their relation to the matter under consideration.
2. *The experiment and the main ideas/concepts:* Present the basic idea or concept and the empirical data arising from history that are essential in the case under consideration.
3. *Impact*: Present the effects of the central idea or empirical evidence in scientific literacy and the teaching of science. Students respond to the following questions: Where do the concepts fit into the science curriculum? How would one present these concepts/ideas/experiments in the classroom? What are the diverse connections of the concepts under discussion? (Stinner et al., 2003, p. 620)

3. Reconstruction materials (replicas) and reproduction of historical experiments. The idea that an experiment can change the course of science is an interesting claim and it is a challenge for the students to reproduce it. It would be ideal to use equipment similar to that used originally by the scientist. Using the same construction procedures and operation of devices which originally the scientists used in their research accomplishes the following, according to Heering, (2003):

- Overcomes the apparent linearity of the development of scientific knowledge.
- Puts students in an unusual situation: The experimental situation is "open," meaning that they do not know what may result from their experiment. The experience is different in the experiments used in the teaching of science. Neither is discussed in textbooks nor are the results of experiments essential according to modern theories.

And finally, the explanation for the rejection of unsuccessful experiments is a much more complicated one. Therefore these examples can allow students to overcome the epistemological position of a single experience. The lack of discussion of unsuccessful experiments can produce a perception of the nature of science that is contrary to original intentions (Heering, 2005).

4. Dramatisation and role play. Theatrical plays based on the controversies involving great scientists (e.g. Copenhagen, involving Heiseberg and Niles Bohr) can be staged by students and presented to audiences. For example, the plays of: Brecht, "The life of Galileo"; Golding: The Physicists; Kipphard: In the Matter of J. Oppenheimer. Unfortunately, these works have not been translated into Greek, except for Brecht's "The Life of Galileo," and it is therefore difficult to transfer some plays into Greek. Besides, such a theater experience is applicable to a more mature audience and, therefore, it is suitable mainly for university classes.

Role play activities in educational settings serve multiple purposes. Students engaged in such activities may take the role – in this case a relevant selection of physical properties mapped onto physiological or social elements – of physical entities like atomic particles or fields. This method is more common in younger children's science education in primary school. Its characteristics may be used to explore the role of models in science. Within an HPS approach, it may serve to present the changing nature of modelling phenomena through history, for example, the differences between fluid-based and particle-based modelling of electricity (Henke et al., 2009). Science drama is expected to provide a humanistic aspect to authorized scientific knowledge by eliciting emotional and active participation. In addition, science stories must consciously incorporate a "scientific element" and a "humanistic element." Even for the simple retelling of "Eureka stories," the crafting of the story is a humanistic, creative process. We can invent stories, but they must be well placed in history (Stinner, 2007).

Yoon (2006) suggests three ways of using science drama in the classroom. Firstly, the setting of the scene should be designed and in the process it provides a useful context for learning. Secondly, drama making is a learning process on its own. The intention is for a great deal of learning to occur during the preparation of science drama. Thirdly, drama as a representation of aspects of natural philosophy offers an assessment opportunity.

5. Biographies of scientists. Stories about the personal lives of scientists stimulate students' interest in science. Discussions just of the methodology followed by each scientist usually lessens students' interest (Seker & Welsh, 2006). For example, Aristotle and Galileo used different scientific methods to produce scientific knowledge. Aristotle based his conclusions on empirical observation, while Galileo performed experiments. A teacher can show how short biographical passages relate to the content being taught.

Undoubtedly there are biographical sources accessible to teachers, but caution is necessary when they are used in teaching practice. It is possible, for example, for children to hear the story of Archimedes' "Eureka" and form the view that scientists spend much time in meditation, trying to solve problems by working on their own (Stinner et al., 2003). We need, therefore, stories from the personal lives of scientists to be directly associated with the content being taught.

6. Thematic narratives. This approach identifies general issues that transcend the boundaries of individual disciplines and may have interdisciplinary and human interactions. These issues transcend individual disciplines and often link important aspects of human activity (Dagenais, 2003; Stinner et al., 2003).

7. WebQuest, simulation of historical experiments and site design. Masson and Vázquez-Abad (2006) propose a way of integrating data from the History and Philosophy of Science in teaching science to achieve conceptual change by introducing the notion of a historical micro-world, which is a computer-based interactive learning environment. Also, in our previous work we presented educational software (CD-rom) about the life and work (for science) of Archimedes (Kokkotas et al., 2003; Stamoulis et al., 2006), which can be used for teaching simple machines in elementary education.

WebQuest is a lesson script, a learning activity that focuses on enabling students, and it is oriented to research. It is a problem-solving activity where students can use various information sources (Web, educational software, contract forms, etc.) (Dodge, 2001; WebQuest Resources). The term WebQuest was first introduced in 1995 by Dodge to describe structured exploratory activities of pupils or students, where most of the information was drawn from the worldwide web. The means used can be hypertext information, databases, electronic data or interviews, discussions, etc., printed conventional material from books, magazines or newspapers, and face-to-face interviews with experts, students can choose from the sources available to them. Biographical data, simulations, anecdotal descriptions of historical experiments, and scientists' authentic texts can be utilized to create a WebQuest to learn the content of science using data from the History and Philosophy of Science.

Conversely, students can collect material to clarify the content, use elements of the story related to the negotiated notion, and upload to a website. This act requires a higher function of thought (organization, classification, abstraction, judgment) and is therefore quite a productive activity for students. However, it needs to be supervised by a teacher.

8. Confrontations. We tend to think that modern science can resolve most issues, but the truth is that the science of the 20th century is full of conflicts; some have been resolved completely and some only partially, while others remain unresolved. Sometimes there are competing theories that seek to lay the foundations of new issues, such as the science of the 18th century, electricity, and the new chemistry of Lavoisier and alchemists, but more often scientific conflicts involve the settling of rival theories (Bevilaqua & Giannetto, 1998; Stinner et al., 2003).

Moreover, the study and use of scientists' conflicts (Galvani and Volta) enriches the teaching of science, motivates students, and makes learning more meaningful. Students understand scientific ideas, scientific methodology, and the nature of science much better through the lives and work of scientists (Malamitsa, Kokkotas, & Stamoulis, 2005).

9. Vignettes. The smallest unit of presentation of historical material may be a short story, carefully selected and linking the concepts and ideas to the study and the interests of students (Stinner et al., 2003). Vignettes of the History and Philosophy of Science are specific activities that can be examined in the context of the activity theory (Engeström, 1999a). In this case, evidence from the History of Science provides tools of mediation, through which social interaction and cooperation can be enhanced to achieve the learning objectives. Carefully selected small vignettes are incorporated organically in worksheets and contribute effectively to mediation in achieving the learning objectives of students. The worksheets can be integrated in a broader context of the story line for a teaching concept.

10. Dialogues. Dialogues between representatives of opposing theories can be presented in class, for example, as dialogues between Copernicus and Aristotle, Priestley and Lavoisier, and others (Stinner et al., 2003). As students try to find examples to support their theory, they begin to understand the process of science. The students voluntarily participate in the discussion. They prepare for discussion by collecting information about the scientist they have chosen to present in the class. The discussion in the classroom is quite often lively and often brings out quite intelligent examples (Dagenais, 2003).

11. Historical thought-experiments. Thought experiments devised by scientists during their research can be tested or verified with our resources. Hypothetical experiments have played an important role in the history of science. Evidence of this is their use by Galileo, Leibniz, Newton, and Carnot and, in the 20th century, by Einstein, Schrödinger, and Heisenberg. According to Matthews (1994) hypothetical experiments can be distinguished into those that are destructive of already accepted theories or conceptual schemes and those that are constructive, or that support new or old theories. Presumptive experiments enable teachers to assess the extent to which students understand the fundamental principles of an axiom; they employ the mind and reveal what the student thinks about the concepts being investigated (Matthews, 1994).

12. A variety of teaching tools such as design and layout of posters, discussions on the occasion of a historical person, etc. This approach shows a great deal of promise for facilitating the use of history of science in science teaching as well as the strong influence that the study of the history of science may have on researchers coming from a variety of fields (science education, history of science, philosophy of science, information and communication technologies in education, art studies, social studies, etc.).

TOWARD TECHNOLOGICAL SUPPORT FOR DESIGN ACTIVITIES

Activity theory puts the general trend for the design of interaction outside of computers and focuses on understanding technology as part of a broader goal of human activity (Kaptelinin & Nardi, 2006). Present times are characterized by the ability to communicate with people anywhere in the world. The introduction of ICT (Information Computer Teaching) in education is now a necessity and a high priority for the educational systems of all countries. However, successfully integrating digital tools into everyday practice is a complex endeavour. The use of technology for educational purposes is currently a common practice. This practice is constructed by society –a product of the values, knowledge, and skills of people. Inevitably, therefore, it is influenced by the social and cultural context in which it develops. Closely connected with this view is the idea that the impact of technology in facilitating students' access to learning is also determined by the pedagogical knowledge and skills of teachers. Technology enables teachers to extend the validity of theories (pedagogical and psychological for learning) the absence of which leaves teachers in mediocrity (Elmore, 2004).

Within the field of social studies computers have served dual roles, as important instructional tools and as objects that have affected the political, social and economic functioning of society. However, the extent to which this potential is being fully realized in the classroom has not been sufficiently explored. Computer-based learning has the potential to facilitate the development of students' decision-making and problem-solving skills, data-processing skills, and communication capabilities. By using computers, students can gain access to extended knowledge links and broaden their exposure to diverse people and perspectives. "According to Vygotsky, whoever adopts the view that art is a means of pleasure and enjoyment, it is likely to encounter strong competitors in sight of the first delicacy to find the child in the way" (Dafermos, 2002). This view of Vygotsky is directly applicable today to computers and their use by students. The impressive design of modern environments, easy access to a plethora of exciting things (games, music, movies, etc.) and information can easily be "treats" for young students and lure them. What we need now is not for the computer to be a delight and pleasure to the child but to provide the necessary impetus to transform the "lower" forms of mental energy into "higher" forms.

To achieve learning, students must be engaged in their learning goal; the computer becomes the intellectual tool that will attempt to mediate the conquest of knowledge. In other words, when students work with computers, they enhance the computer's capabilities and then the computer enhances their thinking and learning. Like carpenters who use tools to build things without being controlled by their tools, so students should use computers as tools to achieve their own goal and to support learning and not be controlled by them and directed in other directions (Jonassen, 2000).

Humans not only created tools and technical resources to subjugate the forces of nature but they also created psychological tools that help to regulate and control mental activity (Dafermos, 2002). It is therefore necessary to escape from a techno-centered prospect where the computer is the focus for understanding technology as part of human activity (Kaptelinin & Nardi, 2006) in the direction that the computer is a tool for mediating the interaction between man and environment. Kozma (2003), in his introduction of technology and innovation in education, defines five criteria for innovation:

1. Changing roles of teachers and students, regarding the objectives of the curriculum, assessment practices, educational material, and infrastructure.
2. The essential role and added value of teaching practices.
2. The relationship of innovation to the achievements of students.
3. The capacity of sustainability and the possibility of spreading innovative practices from one classroom to another in local, national, or international levels.
4. The integration of national issues such as local and cultural particularities.

The first attempts to introduce ICT in education in the 1970s relate mainly to development of teaching systems using the computer (Computer Assisted Instruction CAI or Computer Assisted Learning CAL) and to training programs and "drill and practice." These programs were based mainly on the behavioural theory of learning. This methodology, however, cannot promote complex thinking, problem solving, and the transfer of skills acquired by students in other similar environments (Jonassen, 2000).

> The most sophisticated form of CAI is an intelligent tutoring system (ITS), sometimes referred to as intelligent CAI. ITSs were developed throughout the 1980s and 1990s by artificial intelligence (AI) researchers to teach problem solving and procedural knowledge in a variety of domains. What ITSs add to tutorials is intelligence in the form of student models, expert models, and tutorial models. Expert models describe the thoughts or strategies that an expert would use to solve a problem. How the student performs while trying to solve the problem in the ITS (captured in a student model) is compared with the expert model. When discrepancies occur, the student model is thought to have bugs in it, and the tutorial model diagnoses the problem and provides appropriate remedial instruction. ITSs have more intelligence than traditional tutorials and so can respond more sensitively to learners' misinterpretations. […] In the 1980s, microcomputers proliferated, so educators (as they had with most other technologies like radio, film, and television) began grappling with how to use them. The unfortunate result of their deliberations was that most educators felt that it was important for learners to learn about computers. So, we taught students about the hardware – components of computers. And because useful applications were not available, we taught students how to program the computers, too often using BASIC. […] It is a mistake to believe

> that if students memorize the parts and functions of computers and software, then they will understand and be able to use them. (Jonassen, 2000, pp. 6–7)

According to Kaptelinin and Nardi (2006), whose contributions on activity theory have been influential in the domain of Human Computer Interaction, activity theory is a conceptual framework that enables people "to bridge the gap between motivation and action [and] provides a coherent account for processes at various levels of acting in the world" (Kaptelinin & Nardi, 2006, p. 62). The dialectical relationship between semiotic and technological spaces leads us to consider the concept of functional organs, which is viewed by Kaptelinin and Nardi (2006) as "a key concept of activity theory from the point of view of interaction design" (Kaptelinin & Nardi, 2006, p. 64). According to these authors, "functional organs combine natural human capabilities with artefacts to allow the individual to attain goals that could not be attained otherwise." To create and use functional organs, individuals need a range of competencies.

Tool-related competencies include knowledge of the functionality of a tool, as well as the skills necessary to operate it. Task-related competencies include knowledge about the higher-level goals attainable with the use of a tool and the skills of translating into the tool's functionality (Kaptelinin & Nardi, 2006, pp. 64–65). In addition to creating and using functional organs efficiently, individual subjects also need what Kaptelinin and Nardi call metafunctional competencies, which "enable [the subject's] understanding of how to use functional organs (such as knowing tricks and work-around), recognise their limitations, and know how to maintain and troubleshoot them" (Kaptelinin & Nardi, 2006, p. 218). The above competencies are also required of lecturers who want to efficiently integrate the institution ICT into their teaching practice.

Taking an ICT-mediated lesson in a school as an activity system, the subject is the student and the object is to understand the relationships among the variables found in an ICT-mediated simulation package. A pool of ICT and non-ICT tools, including the simulation package, mediates the interactions between the subject and object. The student belongs to a community consisting of his/her classmates, teachers, and ICT staff mediated by rules and division of labor. The rules include the school disciplinary rules and more specific ones like the procedures necessary to run the simulation program. For the division of labor, the student plays the role of the scientist, by gathering, representing, interpreting, and analyzing data, whereas the teacher takes on mediator role where he/she questions, clarifies, and summarizes to support students' understanding of the relationships among the variables under study (Lim, 2007).

Activity theory seems to be a natural fit in the HCI domain due to its being based on the central concept of the mediating role of tools in human work. However, activity theory, with its long history, wide-ranging complex, and rich approach and theoretical focus, has not lent itself to easy application in the HCI field. Activity theory provides no step-by-step methodology (Duignan et al., 2006).

Applying Activity Theory in Designing an ICT-Based Instructional Package. In this study we propose Engeström's expansive learning as a basis for planning and analyzing activities in science teaching. An activity may be the teaching of a concept of science. For example, let us introduce the concept of electromagnetism in elementary school. This activity is divided into activities that have to do with the creation of the concept of electromagnetism. So for each element which is a prerequisite for conceptual understanding by students of the concept of electromagnetism, there is an activity planned as a teaching/lesson.

For the design of each activity we follow the concept of the expansive cycle, which starts with the accepted practice of an action and leads progressively through the resolution of conflicts arising between the elements of activity, but also among the participants in the activity, to implement new practices. The integration of the cognitive structures of students' concept of electromagnetism is the goal of the instructional intervention that is the object of activity. The results of the activity are perceived through the potential of students to use the concept of electromagnetism or elements of the concept to solve problems of everyday life. The tool that mediates the subjects/students in the performance of the activity, the computer, is chosen as a natural tool, along with data from the History and Philosophy of Science as an intellectual tool.

The rules are set by the operation of the class and confine students to the tasks. The activities in this phase of work are addressed and take into consideration the community of the classroom. They are not extended to the family and the broader sociocultural environment of students for labor-saving. The division of labor is linked to the work of students both as individuals and as a group of a few students or as a group of the whole class. Then we describe the application of cultural-historical activity theory in the teaching intervention and the dialectical relationship between elements of the history of science, technology, and learning through an adapted version of Engeström's expansive activity model. Figure 5 shows the activity of electromagnetism as a drawing with the help of third-generation activity theory. The basic concepts of electromagnetism are taught in separate activities, which are part of the system activities with the common goal of understanding the concept of electromagnetism.

First activity – From toys with magnets in electric and magnetic phenomena. The teaching of the concept of electromagnetism begins by introducing students to the magnetic phenomena and their important function in the magnetism of the earth and the construction of the compass. The outcome of the activity is the use of the compass by students for their orientation and the application of the methodology of the experimentation that was first introduced by Gilbert. The students/subjects of the activity first classify materials with the help of the computer, and then with real objects of various materials both magnetic and nonmagnetic and then learn about the magnetism of the earth and its importance in the construction of the compass.

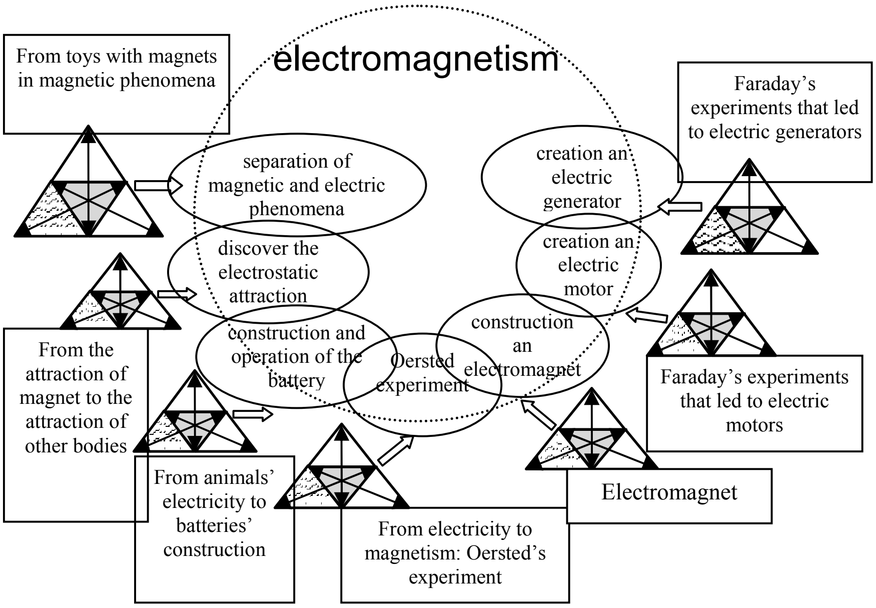

Figure 5. Applying the activity theory in the case of electromagnetism.

This activity is addressed in the class with the intention of achieving the target, a target mediated by a corresponding software and data from the history of science. Students are aware of the attraction of magnets and the model of the earth as a magnet and its importance in the construction of the compass and the orientation of people on earth. The rules and restrictions imposed on the operation of the class and, of course, the participation of each student or group of students in conducting activities, complement the other elements of the activity.

The structure of the activity follows the design of the expansive cycle of Engeström, whereby the first stage consists of a simple power function and creates an incentive and an analysis of the current situation while the scientists have only an empirical study of magnetic phenomena.

The analysis of the situation continues in the second stage, in which students are aware of the efforts of the scientist Gilbert to study magnetic phenomena scientifically. Also at this stage, the role of the earth as a magnet is introduced.

In the third stage of modelling tool which is mediated by the computer, students construct the model of the earth as a huge magnet and experiment.

The evaluation model is effected in the next stage of activity in which students name the poles of the magnet and utilize it in the construction of the compass. Acceptance of the model and the methodology of Gilbert, who studied magnetic phenomena scientifically, seems to help students evaluate the importance of science in developing scientific thinking and experimentation.

This activity is the basic unit of planning and analysis. The higher level of collective activity is directed before the goal of understanding the operation of the compass and magnetism of the earth.

The historicity of the activity allows students to conceive the initial attraction of the magnet to specific materials and the behavior of the earth as a magnet and then to externalise their knowledge by building themselves a compass, by evaluating scientific methodology, and by avoiding myths and beliefs in the interpretation of natural phenomena.

Table 3. The design of the first activity according to the expansive cycle

Questioning	Introduction of the topic (magnetism in ancient Greece)
Analyzing the situation	Students classify various materials into two different categories: those that are attracted to a magnet and those that are not.
Modeling	The model of earth as a magnet.
Examining the new model	Students experiment with the model of the earth as a magnet and know intuitively the dynamic lines.
Implementing the model	Students know the basic application of magnetism of the earth by creating and experimenting with a compass and naming the poles of a magnet.
Reflecting and evaluating	Students discuss the importance of the compass in the development of traveling and discovering the new world.

Second activity – From the attraction of the magnet to the attraction of other objects. In the second activity, students discover electrostatic attraction between opposite charged objects and the repulsion between objects charged with the same charge and recognize the symbolism of the load in positive and negative forms.

This activity is addressed in the classroom; achievement of the goal is mediated by the construction of Gilbert's versorium and the efforts of other scholars such as Du Fay and Franklin, who completed the study of the nature of electricity.

The activity begins with the question of whether there are other bodies in which there is an attraction. In the first stage of the activity there is an incentive to analyze the situation. The students know from everyday life that when the plastic cap of their pen is rubbed, it attracts small pieces of paper. Then they test the model of Gilbert's versorium on their computer. They test plastic material by rubbing it with a woolen cloth and a glass object by rubbing it with plastic, thus distinguishing the two types of electricity.

In the next stage of integration of the model, students are asked to use their own materials to construct the versorium and experiment. While in the process of accepting and evaluating, the students describe and interpret the function of the versorium using the model on the computer.

Table 4. The design of the second activity according to the expansive cycle.

Questioning	Incentive
Analyzing the situation	Students know that apart from magnet's attraction, there's also the electrostatic attraction among bodies
Modeling	Students run the versorium model on their computer.
Examining the new model	Students construct a versorium with real materials and experiment.
Implementing the model	Students know Du Fay's results for the two types of electricity and their denomination.
Reflecting and evaluating	Students give their own interpretation on the operation of the versorium and the nature of electrical loads.

Third activity – From animal electricity to construction of battery. One of the elements necessary for developing the concept of electromagnetism is the construction and operation of the battery, which can be approached in its historical dimension, namely with the construction of the electric battery by Volta. So we designed such an activity, whose outcome is battery usage by students in their everyday life. In this activity the students/subjects of the activity construct a simple battery of Volta with simple materials – the object of the activity mediated by cultural tools of the computer and the famous confrontation between Volta and Galvani on the nature of electricity, i.e., if that electricity is of animal origin or due to an electron flow due to potential difference. This activity is addressed to the class and the target's achievement is mediated by the corresponding software that we developed, through which students become aware of the controversy scientists engaged in over the creation of the model of the battery as well as the construction of a simple battery. The rules and restrictions imposed by the operation of the class and, of course, the participation of each student or group of students in conducting activities, complement the remaining elements of the activity.

The structure of the activity is designed to follow the expansive cycle of Engeström, whereby the first stage is a simple power function and creates an incentive to analyze the current situation, in which scientists can collect electrical loads and use them whenever needed. The analysis continues in the second stage, in which Galvani gives his own interpretation of electricity and the emerging confrontation with Volta. In the third stage of the modeling the tool of mediation is the computer, students construct a virtual model and bring it into operation. The battery of Volta is a fact and, in the next stage, students are asked to accept and integrate the model of Volta's battery, creating a potential difference between two metal electrodes and constructing a battery of simple ingredients (lemon and electrodes of iron and zinc).

The evaluation and acceptance of the model is amplified in the next stage of activity in which students compare a battery that they use in their everyday life with a battery constructed by Volta, which they constructed first on the computer and then with simple materials. This activity is a basic unit of planning and analysis. The higher level of collective activity is directed before the goal of understanding the operation of the battery.

Table 5. The design of the third activity according to the expansive cycle.

Questioning	Incentive
Analyzing the situation	Students know the views of the two scientists (Galvani and Volta) as well as their antagonism.
Modeling	Students construct a model of a virtual battery on the computer screen.
Examining the new model	The students bring into operation the model they constructed.
Implementing the model	Students create a potential difference between two metal electrodes by constructing a battery with simple materials (lemon and electrodes of iron and zinc).
Reflecting and evaluating	Students compare a battery used in their everyday life with a battery constructed by Volta, as they also constructed a virtual one first on the computer and then with simple materials.

This structure and comparison of the batteries they use every day is incorporated into their cognitive structures and allows them to internalize the operation of the battery and use it easily in their everyday life. The activity about the opposing scientists, Volta and Galvani, also reveals the contradiction that allowed both scientists and students to create electricity

Fourth activity – From electricity to magnetism: Øersted's experiment. The concept of electromagnetism is accomplished by teaching Øersted's experiment, which underlies the relationship between electricity and magnetism. The outcome of this activity is for students to understand the relationship between electric and magnetic phenomena. The students/subjects of the activity test the experiment's model on the computer and then construct it themselves with actual materials.

This activity is addressed in the class, and the objective is mediated by corresponding software and the historical experiment of Øersted and other elements from the history of science. The rules and restrictions imposed by the operation of the class and, of course, the participation of each student or group of students in conducting activities complement the rest of the elements of the activity.

The structure of the activity is designed to follow the expansive cycle of Engeström, whereby the first stage is a simple power function and creates an incentive for analyzing the current situation, which is that scientists have been trying for many years to discover if there is a relationship between electricity and magnetism in order to achieve integration of these two concepts.

Table 6. The design of the fourth activity according to the expansive cycle.

Questioning	Incentive and analysis.
Analyzing the situation	Students know the efforts of scientists and discover the relationship between electric and magnetic phenomena.
Modeling	Students virtually construct the model of Øersted's experiment on the computer screen and test it.
Examining the new model	The students bring into operation the model on the computer, along with the one they constructed with real materials.
Implementing the model	Students apply what they learned in the construction of the experiment on a problem of everyday life in interpreting the disorientation of a compass from lightning.
Reflecting and evaluating	Students accept the relationship between electricity and magnetism and try to convince the captains of the ships that the electricity in the lightning is what caused the disorientation of the compasses.

In the second stage of the activity the students learn from the original description of the experiment by the scientist himself; they are puzzled and then acknowledge that great achievements in science occur over a period of time, after having been preceded by several failed attempts to reach the goal.

In the third stage of the modeling tool mediation computer, students construct the model of Øersted's experiment on the computer and monitor its progress.

The model's evaluation is effected in the next stage of activity, in which students try to interpret a real event that happened to a fleet in the Atlantic Ocean when, after a storm, compasses became disoriented. The interpretation and the creation of an imaginary dialogue between the captains of the ships with Øersted allow students to accept the relationship discovered by the scientist and use it in everyday life. This helps students to interpret phenomena scientifically and evaluate the importance of scientific thinking and experimentation in the development of science.

This activity is the basic unit of planning and analysis. The higher level of collective activity is directed towards the goal of understanding the relationship of electricity to magnetism.

Fifth activity – From electricity to magnetism – electromagnet. The discovery of the relationship between electricity and magnetism by Øersted triggered significant inventions that laid the foundations of modern civilization. One of these is the invention of the electromagnet. The main part of this activity is for students to realize the various applications related to the discovery of the relationship between magnetic and electrical phenomena, especially the electromagnet.

This activity is addressed in the classroom and the objective is mediated by historical evidence of the efforts of scientists to apply in practice the relationship between electricity and magnetism and the construction of an electromagnet on the computer first and then with real materials.

Table 7. The design of the fifth activity according to the expansive cycle.

Questioning	Introduction of the topic under discussion. Students are familiar with the efforts of scientists in the early 19th century to create practical applications that demonstrate the relationship of electricity and magnetism.
Analyzing the situation	Students experiment by constructing a coil to detect the presence of magnetic field.
Modeling	Students construct the model of an electromagnet on the computer screen and experiment with it.
Examining the new model	Students construct an electromagnet with real materials and test it on computer.
Implementing the model	Students apply the operation principle of the electromagnet's construction. They are familiar with its operation and they describe it.
Reflecting and evaluating	Students find and discuss various applications of the electromagnet in everyday life.

The activity begins with a vignette from the history of science that shows the continued effort of scientists in the early 19th century to find practical applications for connecting electricity with magnetism. Particularly highlighted are the efforts of André Marie Ampère and the construction of the coil and magnetic field. (It is worth noting that there is no reference for the students about the meaning of the field, something they perceive only intuitively.) In the first stage of the activity, the situation is analyzed, creating an incentive. Students are familiar with the coil and create its model on the computer. Then they construct a coil and find out through experimentation that the coil behaves as a magnet and is even more powerful than a simple current-carrying conductor. They place a core in the coil and find out that the attractive force of construction is multiplied. In this way, they construct a magnet and manage to control its action as long as they wish while the pulling power is not present when the coil does not have an electricity flow.

In the next stage of integration of the model the students are asked to describe the operation of the electric bell. This device is in their school, and they experience its operation on a daily basis. Seeing the model of the bell on the computer or in the classroom and a real bell enables them to verify the implementation of the electromagnet in devices of everyday life and recognize the value of the construction of the electromagnet. In the process of accepting and evaluating, students are asked to find other devices that make use of the electromagnet. They evaluate its importance in pictures of devices and find other examples.

Sixth activity – New discoveries that changed the world – the motor. The relationship between electricity and magnetism was completed by Faraday, whose contribution was catalytic. In the next two activities, students complete their study on the relationship of power with magnetic phenomena and their interactions.

In the first activity the students/subjects are familiar with the working principle of the electric motor and construct their own motor with simple materials; this project is the subject of activity mediated by cultural tools of the computer and Faraday's efforts to construct the electric motor. In this activity, the objective is mediated by a corresponding software through which students become aware of Faraday's efforts to construct a model of an electric motor. The rules and restrictions imposed by operation of the class, and of course the participation of each student or group of students in conducting activities complement the rest of the elements of the activity.

The structure of the activity follows the design of the expansive cycle of Engeström, whereby the first stage is a simple power function, creating an incentive, while in the second stage the current situation is analyzed: Scientists have reached an impasse regarding the interpretation of the relationship between electricity and magnetism, and Faraday's concerns bring new challenges to the scientific community.

Table 8. The design of the sixth activity according to the expansive cycle.

Questioning	Introduction of the topic under discussion. Students are familiar with a leading scientist, Michael Faraday, and the problem he was asked to account for in the interpretation of electromagnetism.
Analyzing the situation	Students summarize Faraday's concerns and the situation that existed during the second and third decades of the 19th century in the field of electromagnetism.
Modeling	Students follow the model of Faraday's experiment on the computer, acknowledge its parts, and monitor its operation.
Examining the new model	The students put the model into operation. They try to construct it with simple materials and describe its function.
Implementing the model	Students using the construction of Faraday's motor give their own interpretation and describe its operation principle.
Reflecting and evaluating	Students find and discuss various applications of the electric motor in everyday life.

In the third stage of the mediation of the modeling tool computer, students construct a virtual model of Faraday's motor and put it into operation. The electric motor is a fact, and students are invited to proceed to the next stage to accept and integrate Faraday's model, which they have created with simple materials (a magnet, a battery, and a coil) and thus produced a prototype motor.

The evaluation and acceptance of the model is amplified in the next stage of activity, in which students give their own interpretations and describe the operation of the motor. Finally they find devices from everyday life and discuss the motor's uses in these devices.

Seventh activity – New discoveries that changed the world – the generator. One question which troubled Faraday remained to be answered to complete the connection of electricity with magnetism: Once a pipeline that is powered by electric current behaves like a magnet, what would happen if a magnet moved in a circular pipe?

In this activity the students/subjects answer Faraday's question by integrating the relationship of electricity with magnetism with an electric current by moving a magnet inside a coil, which is the subject of the activity with the mediation of the computer's cultural tools and the construction of the first single generator by Faraday.

In this activity, the objective is mediated by the software we developed, in which students experiment with the model of Faraday's electrical generator. The rules and restrictions imposed by the operation of the class and of course the participation of each student or group of students in conducting activities complement the rest of the elements of the activity.

Table 9. The design of the seventh activity according to the expansive cycle

Questioning	Students are puzzled by the question that troubled Faraday.
Analyzing the situation	Students analyze the situation as it has been formed with the construction of the electromagnet and the motor.
Modeling	Students construct a virtual model of an electric generator on the computer screen.
Examining the new model	Students put the constructed model into operation.
Implementing the model	Students describe the creation of electric power in factories using the electric generator.
Reflecting and evaluating	Students express their views about the importance of Faraday's work and about the electricity as a foundation of modern civilization.

The structure of the activity follows the design of the expansive cycle of Engeström, whereby in the first and second stages, students are concerned with the question which troubled Faraday and analyze the situation as it had been introduced thus far: The magnetic needle deviates when located near a current-carrying conductor, the attraction takes place when the conductor is circular (coil), and results in the construction of the electromagnet by Henry and of the electric motor by Faraday.

In the third stage of the modeling tool mediation computer, students construct a virtual model of the generator and put it into operation. This results in the production of electricity. The construction of electric power is a fact and students are invited to the next stage to accept and integrate Faraday's model through their knowledge that the electricity reaching their homes is created in this way in power stations.

The evaluation and acceptance of the model is amplified in the next stage of activity, in which students evaluate the importance of electricity generation in modern culture.

Discussion and Further Research

In order to evaluate the design of the teaching package, we implemented it in a primary school class. Moving to the analysis of a complete activity, the mediation offered by the system can be studied based on three levels: epistemological, methodological, and social interaction (reciprocal help) (Bottino et al., 1999). Each of these three levels expresses the role of mediation in relation to each of the components of the mediation activity (tools, rules, division of labor) in the reference model activity.

1. *Epistemological level.* This level deals with the historical and cultural development of the object (in our case the goal of teaching) and the contradictions that characterize this evolution. The analysis at this level takes into account the characteristics of the used tools that are ICT and the history and philosophy of science, incorporating a specific culture that affects the activity itself. That is, how can the tool support learning about the subject of activity and how can it enable the automation of new working methods and construct new tools for activities of real life?

- Students worked in a context in which the scientists dispute about the nature of electricity emerged.
- They conducted substantial activities on the computer to understand the creation of direct current power.
- They conducted activities with materials that verified the model by creating power introduced by the computer.
- They developed skills for applying and comparing the model to real life situations.

2. *Methodological level.* At this level, the analysis is related to the actions and targets involved in the activity mediated by tools. Here it is necessary to understand how the use of tools can support the acquisition of a methodology for achieving the objective of the activity. The support tool includes the construction of new modes of communication structure in the activity.

The tools used by students (the computer and the history and philosophy of science) made it possible for students to:

- Manipulate objects in a context where they could give meaning to problem-solving activities.
- Convert objects that represent abstract concepts with the help of feedback.
- Connect, with a suitable connection, the elements with specific actions for handling objects.
- Create appropriate and useful communication actions to resolve the contradictions that have emerged throughout the learning situation.

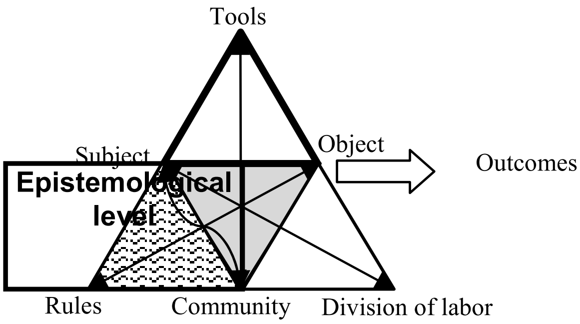

Figure 6. The analysis of activity with emphasis on the epistemological level.

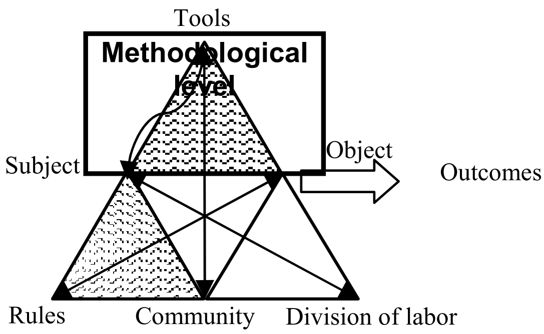

Figure 7. The analysis of activity with emphasis on the methodological level.

3. *Level of social interaction.* The changes in the structure of social relations are considered along with new roles introduced by the mediation tools. The importance of these changes is taken into account in order to create new forms of assistance that might better meet the needs of students. The important issue on this level is the support of students within the zone of forthcoming development as a key link in the development of learning (Vygotsky, 1978).

- The students posed questions that led to the acquisition of skills for designing a solution strategy.
- They offered examples of an effective course of action.
- They generalized.

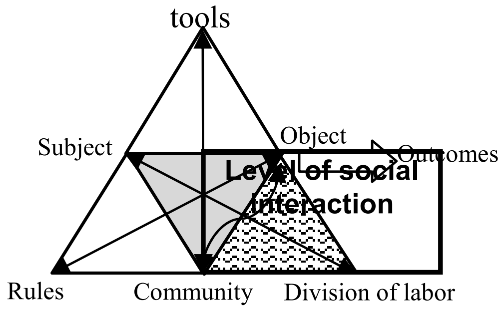

Figure 8. The analysis of activity with emphasis on the level of social interaction

CONCLUSIONS

In our project we propose a methodology for the design and analysis of activities in science teaching in primary education that relies on a corresponding proposal for teaching mathematics (Bottino et al., 1999) that is based on activity theory and expansive learning as formulated and implemented by Engeström.

Our methodology includes design activities within the stages of an expansive cycle (question, analysis, modeling, application of the model, evaluation, and acceptance). For each stage, an appropriate action was designed for students to help them internalize the concept/purpose of the activity.

In the first activity the goal/object was the separation of magnetic and electric phenomena, as introduced by Gilbert. In this activity the students worked on the computer and then used real materials to formulate a scientific method of experimentation such as that first introduced by Gilbert. In the second activity students discover electrostatic attraction. We used vignettes of historic figures from the work of Gilbert, du Fay, and Franklin. In the third activity the goal was the construction and operation of the battery. The confrontation between Volta and Galvani was the basic idea around which the students worked to understand the operation and construction of the battery. In the fourth activity, the students/subjects examine Øersted's model experiment on the computer and then perform the experiment themselves with real materials. In the fifth activity, students construct an electromagnet. In the last two activities, which are inspired by the life and work of Faraday, students use software and elements from the history and philosophy of science to create an electric generator and an electric motor.

The methodology also includes the analysis of the components of the activity (subject, object, community), their mutual relations, and entities that mediate these relationships (tools, rules, division of labor). In such a context we analyze the activity from three perspectives: epistemological-methodological, social interaction, and mutual aid. These three perspectives are respectively related to the relations of subject-community, subject-object, and object-community, which are affected by the mediation resulting from the use of new technologies and data from the history and philosophy of science.

The students worked in a context that includes many years of effort spent by scientists to prove the unity of electric and magnetic phenomena; they performed activities on the computer, and using real materials, they handled objects and created relevant and useful communication actions that resolved the contradictions, raised questions, and made generalizations.

The results of the case study that we examined showed that the mediation of the tools used (software, data from the history and philosophy of science) and the examples offered to help students, played a key role in the activity's success. The students provided a solution to the conflict over what creates electricity, and concluded the structure of the concept.

At this point I agree with Yves Clot (2009, p. 302), who states that three results have been obtained from Engeström's contribution to the development of intervention studies in workplaces and curriculum in science education. The first result stresses that action for transforming work is the condition of the production of scientific knowledge. The second result attests to the importance of the collective in the development of activity. The third result concerns the question of models in the intervention. The development of the scientific concepts of the interventionist and the spontaneous concepts in the action of the professionals is accomplished along lines that cross but do not become identical.

The encouraging results of our efforts point to the need for further investigation of this methodology in more activities, and we intend to initiate such investigations in the near future.

NOTES

[1] Yrjö Engeström: Learning by expanding: Ten Years after, Introduction to the German edition of *Learning by Expanding*, published in 1999 under the title *Lernen durch Expansion* (Marburg: BdWi-Verlag; translated by Falk Seeger); also in the Japanese edition, published in 1999 under the title *Kakucho ni yoru Gakushu* (Tokyo: Shin-yo-sha; translated by a group led by Katsuhiro Yamazumi). http://lchc.ucsd.edu/MCA/ Paper/Engestrom/expanding/intro.htm.

[2] Greek philosopher Thales of Miletus (~624–547 BC).

[3] It was Plato (427–347 BC) in the 4th-century BC who first made a reference that has survived to the present day on "… that marvellous attraction exercised by amber and by the lodestone …" in one of his dialogues, the Timaeus.

[4] On this point see Dagenai (2003): The following scientists-Aristotle (384 BC–322 BC), Copernicus (1473–1543), Galileo (1564–1642), Newton (1650–1727), Watt (1736–1819), Young (1773–1829) and Bohr (1885–1962) can form the basis for creating a story line. In addition, Gilbert (1544–1603), DuFay (1698–1739), Franklin (1706–1790), Galvani (1737–1798), Volta (1745–1827), Ørsted (1777–1851), Ampère (1775–1835), and Faraday (1791–1867) formed the basis for creating story lines in the context of Science Teacher e-Training (STeT) program: Teaching Science using case studies from the History of EU Science (Comenius 2.1) http://valanides.org/ScienceTeaching/Lessonplans/tabid/78/Default.aspx .

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