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9. BIOLOGY EDUCATION IN ELEMENTARY SCHOOLS

How Do Students Learn about Plant Functions?

INTRODUCTION

This study reports part of a wider project inspired by sociocultural theory, which was designed to investigate and improve pre- and in-service teachers' training on topics related to living things. The main purpose of the whole project is to design and develop helpful teaching materials, supporting tools, and a teacher education curriculum for living things.

The project was influenced by the continuing and growing interest of global educational community in the teaching of natural sciences at all levels of education (AAAS, 1989; OECD, 2007; Osborne & Dillon, 2008). In 2004, the European Union issued a study entitled "Europe Needs More Scientists," thus placing a high priority on science education (EC, 2004).

Considering this priority, we investigate innovative processes and practices in pre- and in-service teachers' training about living things. Living things is a topic that most science curricula include in the very early years of schooling as foundational knowledge. However, research has shown that even in late elementary school there is a significant proportion of students who do not have an understanding of the concept of living things that corresponds with biological theory (Venville, 2004).

The theoretical framework is the cultural-historical activity theory (CHAT) that is inherently developed to understand the use of tools in human activity (Van Eijck & Roth, 2007). Learning in general, and science teacher education more specifically, can be seen as sites for social participation where cultural enactment occurs (Espinet & Ramos, 2009). The activity theorists argue that CHAT is a coherent theoretical framework which establishes science education as participation in the community (Roth & Lee, 2004). Moreover, as we posed in Chapter 1, CHAT bridges the gap between theory and praxis. Also, it aims to achieve the scope of interdisciplinary science education in multicultural Europe. Consequently, a new mentality has emerged which is concerned with situating science education as part of the society. This could reform science education from the inside in a natural and logical way, while lifelong learning activities take place in|for the community, which is inseparable from individuals (Plakitsi, 2009).

K. Plakitsi (ed.), Activity Theory in Formal and Informal Science Education, 229–251.

This study is a pilot research study which aims to investigate how primary school students conceptualize plant functions while students are involved with different systems of activities. The study promotes a bottom-up approach, which helps the young children's cognitive development concerning plant functions and also the development of school teachers' training programs in teaching science.

Based on the CHAT theoretical framework, we undertook a pilot implementation on teaching living things to a class of 16 primary students who were 10 to 11 years old (5^{th} grade). We studied the way they conceptualize integrated concepts, for example, the system of living|non-living things and the system of photosynthesis|respiration|transpiration. We choose the dialectical symbol |, because we think of living at the same time as thinking of non living things. A living thing exists at one moment while it cannot exist at another and vice versa. So, we cannot conceptualize a living thing without simultaneously conceptualize a non living thing. On the other hand, photosynthesis and transpiration and respiration form a unit considered as plant functions. We failed in teaching those functions in isolation and, now, we test them with a systemic teaching approach. The teacher acts as researcher too, so we use the term teacher|researcher. The teacher was a female and she designed a sequence of tasks in order to help students to acquire learning about plant functions. Overall, our approach for the unit "Plants" was holistic, since our basic teaching objective is students coming to understand plants as living things with dynamic interactive and interdependent functions. So innovative teaching took place without using the current school textbooks on natural sciences, but using our own worksheets, which we had prepared for the purposes of the pilot study. Plants and their functions constitute a whole that cannot be divided into subunits (especially when the students are from 10 to 11 years old).

The analysis of the activities gave us a large number of answers, but also raised new research questions. Using CHAT for science education in the field of living things seems promising. In addition, this theoretical framework seems to be appropriate and fruitful for teachers|researchers' education in primary science teaching. The experimentation on new processes in natural science pedagogical actions in the wider system of activities demonstrates the importance of CHAT for science education, and encourages us to continue our studies in this research field. This case study, even though limited, could actuate the discussion of cultural studies of science education, especially teacher training for applications of the CHAT framework in science education.

RATIONALE

The rationale contains the general problem, the specific problem of teaching plant functions, the innovative teaching proposal following a didactical transformation, the multiple levels of expected outcomes and the necessity of choosing the CHAT framework.

General problem: In recent years, many countries have reformed their science curriculum. Major agencies stress the need for scientific literacy and develop programs for both evaluating the results of the teaching of science (Programme for International Student Assessment – PISA) and for the promotion of science (Project 2061).

For this purpose the Greek Ministry of Education changed the curriculum in 2003 towards Cross Curricular/Thematic Framework (CCTF) and the Individual Subject Curricula for compulsory education, which introduced a cross-thematic approach to learning. Educational change in Greece focused on the preservation of national identity and cultural heritage, on the one hand, and the development of European citizenship awareness, on the other. The final curriculum is the end product of a long, strenuous, and collaborative effort of teachers, educational administrators, and scientific societies with the co-ordination of the Greek Pedagogical Institute. Currently, this book's editor, Katerina Plakitsi is co-ordinating an ongoing reform towards a new curriculum for the new school of the 21st century. This new curriculum is now in its pilot implementation and testing. Our pilot research dovetails the two curricula enhancing inquiry based learning and the cultural dimension of science education.

In both curricula, the teaching of natural sciences in compulsory education in Greece and especially in primary schools is integrated (including physics, chemistry, biology, geology, and geography) into the subject called "Studies of the Environment," taught in the first four grades, and in the subject called "Explore the Natural World," taught in the last two grades. One exception is geography, which is taught as an independent subject in the last two grades of primary school.

According to the new pilot curriculum for Natural Sciences, the aim of teaching science in compulsory education is incorporated in the general aims of education, which are the well-rounded and balanced development of the individual through the development of critical thinking abilities and a positive attitude towards creative action on a personal and a social level. In our approach we try to move the discussion more from the society to the individual and less from the individual to the society. The new curriculum for Natural Sciences sets as priorities:

- the respect for cultural diversity and gender equality
- the promotion of personal and social recognition
- The motivation of the student towards democratic and civic participation.

The innovation of the new curriculum for natural sciences is at multiple levels. The main innovative aspects of this curriculum are:

- the networking of concepts,
- the attempt to create authentic learning environments,
- the attempt of cultivate the language and especially the argument,
- the absorbtion of Information and Communication Technologies (ICT) as an integral part of teaching science,
- the opening of science to society and culture,
- the cultivation of elements from the Nature of Science,
- the development of skills from the world of Science and Technology and their transformation into abilities for the modern citizen.

Especially, the new pilot curriculum includes a major thematic unit called “The life around us” where the module of living things is dominant in all grades of primary school.

The specific problem of teaching plant functions: The module of living things is a main subject of biology which is a subfield of natural sciences and concerns the study of life in living organisms such as plants, animals, fungi, protista, bacteria, and all other forms of life. Most science curricula include it in the very early years of schooling as foundational knowledge. However, research has shown that even in late elementary school there is a significant proportion of students who do not have an understanding of the concept of living things that corresponds with biological theory (Venville, 2004). That the biology course includes lots of abstract concepts may cause students to have difficulty in constructing knowledge (Keles and Kefeli, 2010). In our opinion, we may have failed because we teach living things in unauthentic learning environments and often withoutt any enactment of learning communities.

Moreover, this pilot researching study faces the problem of inadequate teaching of plant functions. Plant functions are a difficult biological topic for the students, partially because they are characterized by a number of conceptions that usually make the teaching of these concepts inadequate (Canal, 1999; Carlsson, 2002; Keles & Kefeli, 2010; Lumpe & Staver, 1995; Marmaroti & Galanopoulou, 2006; Yelminez & Tekkaya, 2006).

The concepts of respiration and photosynthesis are important in the wider context of ecological understanding. For example, Lumpe and Staver (1995) report that for students to begin to understand life and life processes, they must understand the concepts associated with plant nutrition. Biologists and biology educators state that understanding energy issues in organisms, namely respiration and photosynthesis, is key to understanding more global issues, such as energy flow, food supplies, and other ecological principles. Nevertheless, during her research related to ecological understanding Carlsson states (2002), in summary, that photosynthesis is understood in many different ways and that the process of respiration in general, and in plants in particular, is unknown to a majority of students.

In depth, and according to a study by Yelminez and Tekkaya (2006), students’ conceptualizations of photosynthesis and respiration in plants are:

1. Carbon dioxide is used in respiration, which only occurs in green plants when there is no light energy to photosynthesize.
2. Respiration in plants takes place in the cells of the leaves only.
3. Respiration is the exchange of carbon dioxide and oxygen gases through plant stomata.
4. Green plants take in carbon dioxide and give off oxygen when they respire.
5. Green plants respire only at night, when there is no light energy.
6. Green plants do not respire; they only photosynthesize.
7. Photosynthesis provides energy for plant growth.
8. Plants respire when they cannot obtain enough energy from photosynthesis, and animals respire continuously because they cannot photosynthesize.

Canal (1999) argues that the common conceptions in primary school students regarding green plant nutrition are:

1. Plant nutrition is the process through which plants feed themselves.
2. Plants are nourished by the substances that they take from the earth through their roots: water and mineral substances.
3. The substances that plants absorb from the earth form raw sap, which moves through the stalk and which allows the plant to grow and carry out its other vital functions.
4. Sunlight is indispensable for the health of green plants, their strength, and good color. Without light, they become weak and may end up dying.
5. Plants breathe like animals, taking in and expelling air. If they do not do so continuously, they asphyxiate and die, like people.

The innovative teaching proposal following a didactical transformation: This pilot study attempts an innovative teaching proposal concerned with the didactical content matter and investigates the conceptualizations that children make about the processes of plants (photosynthesis, respiration, transpiration). For this purpose we proposed a unified topic of plants processes and taught it to primary school students of 10 to 11 years old.

Our teaching proposal tries to integrate the concepts of photosynthesis – respiration – transpiration in a common context and in this way overcoming the students' difficulties in learning these concepts. These concepts are dynamic interactive and interdependent processes, and not separate processes, which means that each process interacts with each other and depends on the others.

More specifically, plants, as living organisms, respire and by this process obtain oxygen and remove carbon dioxide. Photosynthesis is the process of converting light energy to chemical energy and storing it in the bonds of sugar. Respiration is the process where cells use this food (sugar) to release stored energy. So, respiration and photosynthesis are closely related and opposite processes. The complex substances (sugar) which formed during photosynthesis are broken down into simpler ones in a process which uses oxygen (respiration). On the other hand, water in the roots is pulled through the plant by transpiration (loss of water vapor through the stomata of the leaves). Transpiration uses about 90% of the water that enters the plant. The other 10% is an ingredient in photosynthesis and cell growth. Without the process of transpiration, plants would not be able to complete their food production or photosynthesis.

This study sees the plant processes in the context of living systems and supports the connection of elementary science to everyday life. Despite the many difficulties students have in understanding the concepts of plant processes, these processes play important roles in the understanding of many aspects of living systems. Also, one of the aims of science education is to make students learn meaningfully and use their learning to satisfy their needs in daily life. In this sense, considering all above studies and researchers, we designed this pilot study to achieve two broad goals: (1) examine students' conceptualization about living things and (2) develop school teachers' training programs in teaching science.

The multiple levels of expected outcomes: Our innovative teaching proposal traces new paths in elementary science education and meets the cultural – historical activity theory framework. It is well-known that every science has its own epistemology, methods, methodology and consequently its own specificities. In this sense, science education is a field with its own specificities that are not found in other fields. As Katerina Plakitsi mentioned in Chapter 3, typically science education takes place in a school and is structured by a curriculum (formal science education). At the same time, science education could include out-of-school sites, such as science centres, museums, media, community-based programs, and new digital learning environments (informal science education). In any case, science education comprises science content, teaching pedagogy and social science.

As stated in previous chapters, according to the curricula for natural sciences, teaching science has some general aims on a personal and social level, which are well-connected with scientific knowledge and scientific literacy. But science education refers not only to the science content, but also to pedagogical and social practices. Teaching and learning science occurs in a social-cultural context and so we do not only focus on science content. This aspect can be more obvious, through the expected outcomes of science education.

Below we pose the expected outcomes of science education, focused on the topic of plant functions that we studied in our pilot research.

Students of 10 to 11 years old should:

- Be able to identify the parts of a plant.
- Explain in simple terms the function of photosynthesis.
- Find out experimentally that plants breathe.
- Explain that the functions of photosynthesis and respiration are contrary processes.
- Find out experimentally the function of transpiration.

- Feel a sense of satisfaction brought about by being engaged with science and natural phenomena, such as plant functions.
- Develop positive attitudes and values about life and living things.
- Develop interest in exploring nature.
- Acquire motivation to learn science.

- Develop skills in arranging experiments.
- Develop creativity through active participation.
- Develop communication skills, such as non-discursive communication (body language, facial expressions, etc.).

The necessity of choosing the CHAT framework: All above specificities of science education gave us the impetus to study all the interactions taking place during the teaching through the theoretical framework of CHAT. CHAT gives this appropriate context to study these interactions and to analyse most aspects of science education.

Also, given that there is much research on science education, only a few studies use CHAT. The activity theorists argue that CHAT is a coherent theoretical framework which establishes science education as participation in the community (Roth and Lee, 2004). It aims to achieve the scope of interdisciplinary science education in multicultural Europe and situates science education as part of the society.

METHODS

This exploratory research used a case study design and qualitative data collection methods to investigate the process of learning when 10-year-old students (5th grade) are learning about plants and their functions in the context of CHAT. We studied the way they conceptualize integrated concepts of plant functions (photosynthesis-respiration-transpiration). The research methodology followed a qualitative design, involving classroom observations and content analysis. We collected data by videorecordings and analyzed how biology education is progressing at schools under the CHAT framework. Tobin (2006) argues that research in classrooms focuses on better understanding of teaching and learning and using what is learned to create and sustain improved learning environments.

The sample used in this pilot study consisted of 16 students in primary school (5th grade) from the island of Corfu. All of them were in mixed-ability groups and had not received any instruction about plant functions in previous lessons on natural sciences.

Eftychia, acting as teacher|researcher has 4 years of teaching experience in the early years of schooling. She participated in the study anticipating that the expected feedback about children's conceptualizations of plant functions can be used to plan future teaching approaches. The research consisted of 3 days of out-of-school in-service training of the teacher|researcher, 4 days in class preparation of the experiments, and 1 day in-class teaching. The 16 students were from mixed cultural and socioeconomic backgrounds, including children whose parents originated from Greece, Albania, and the Czech Republic. The teacher|researcher informed parents and guardians of all children in the class about the research and informed them of their right to withdraw their child from participation in the research at any time. No parent or guardian chose to withdraw a child from this research. Students also were informed in simple terms about the reasons for the researcher's presence in the classroom and were given the choice of whether they wanted to participate or not. No student decided to withdraw from the research.

According to the Greek National Curriculum, natural sciences lessons in 5th and 6th grades of primary school should take place three times a week (3 different teaching hours). But the school science textbooks keep an old and traditional module of plants consisting of four separate lessons, which are taught during four different teaching hours. The four lessons are (a) The Parts of Plants, (b) Photosynthesis, (c) Respiration, and (d) Transpiration. Our teaching approach was partly based on the above lessons (as we kept the same experiments), but took place in a different articulation. Our approach for the unit "Plants" was holistic, since our basic teaching objective is students coming to understand plants as living things with dynamic interactive and interdependent functions. So the innovative implementation took place without using the current school science textbooks, but using our own worksheets, which we had prepared for the purposes of research (see Appendixes I, II, III). The innovative implementation lasted almost 1 school day (4 teaching hours), since we wanted to approach the unit "Plants" within the same day and not to teach the three plant functions separately on different days. Plants and their functions constitute a whole, which cannot be divided into subunits (especially for students aged 10 to 11 years old).

The innovative implementation consisted of two different parts: one part of preparation and one part of class teaching. Both parts were done with the cooperation of the teacher|researcher and students. Also, the teacher|researcher designed the instruction according to the interests of students. For 4 days (Monday-Thursday) students and teacher|researcher collected the materials for the experiments and prepared the experiments, since most of them needed more than 1 day to be prepared (see Figures 1 and 2). For example, they had to cover some leaves of a plant with foil for 3 days, before studying what happens to leaves without light (photosynthesis).

The teaching of plant functions occurred on Friday, when all experiments were ready. That day was named by students "The Flower Day," since they were very excited about the expected teaching. The main teaching strategy was the creation of cooperative groups of students and the study of cooperative learning according to the CHAT framework. The teacher|researcher divided students into four groups (four students each), using a cooperative approach for each group. The research methodology followed a qualitative design, involving classroom observations and content analysis.

Figure 1. Students are preparing the experiment for respiration 3 days before the lesson (photo from author's archive).

Figure 2. Students are preparing the experiment for transpiration 4 days before the lesson (photo from author's archive).

The teacher|researcher designed a series of learning tasks so that students could approach inquiry based learning about plant functions. At first, teaching plant functions started with a review of plant parts and what plants need to grow. All students had some prior knowledge of both of these concepts. Each student was asked to say his/her opinion about the plants' needs for growth. Most students answered "sunshine, water, and soil." The teacher|researcher introduced students to the new concepts by presenting them with a computer-aided presentation about the three main plant functions. The presentation contained mainly shapes and images, since the new terms were very difficult for most children to understand (see Figures 3 and 4). According to the Mauseth (2009), the definitions of these three concepts of biology education are:

Photosynthesis is the combination of carbon dioxide with water to form carbohydrates in the presence of light.

Respiration is the process that breaks down complex carbon compounds into simpler molecules and simultaneously generates the ATP used to power other metabolic processes.

Transpiration causes leaf cells to lose water.

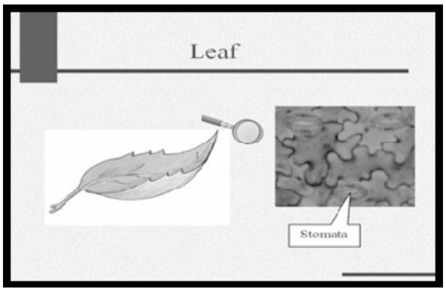

Figure 3. Slide presentation for the structure of leaf (photo from author's archive).

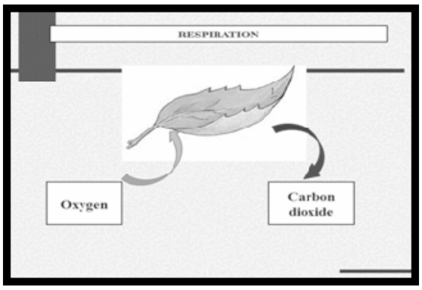

Figure 4. Slide presentation for the plant respiration (photo from author's archive).

After teacher|researcher's presentation the, students moved on to the next actions: the experimental testing and implementation of the new learning concepts. These actions took place through a series of teaching strategies, mainly through collaborative work between students and teacher during the experiments. For this reason, the teacher|researcher gave the students a worksheet (one for each group), in which they had to work and do the experiments (see Appendix I). The sequence of experiments was as follows (the items below are outcomes but not the experiments themselves.)

1. Finding out that humans expire carbon dioxide when they breathe out.
2. Discovering that plants also exhale carbon dioxide.
3. Finding out that certain foods contain starch.
4. Discovering that leaves contain starch also.
5. Discovering that leaves turn yellow if there is no light.
6. Discovering that yellowed leaves contain no starch.
7. Discovering that plants lose water into the atmosphere.
8. Discovering that plants lose water through their leaves.
9. Discovering that plants lose water mainly through the lower surfaces of their leaves.

All experiments involved observations, collecting data by students, who worked in groups as they conducted the experiments. During the experiments, very often students asked their teacher to go back to the presentation to discuss some concepts or to check their results of the experiments. This procedure gave students a positive feedback and supported their learning about plant functions. This was mainly achieved through discussion among teacher and students and among groups. Simultaneously, the teacher|researcher gave the groups another two worksheets, on which the students had to check their understanding about the new concepts (see Appendixes II and III). In this way the teacher|researcher evaluated what students had learned and if the teaching was effective. Both worksheets were of varying levels of difficulty for students and necessitated the cooperation of group members and the development of critical thinking. Open-ended questions and problems from everyday life were selected, instead of multiple-choice or closed-ended questions.

Students had to compose their thoughts and what they had learned in order to answer the questions. For example, in worksheet B students had the opportunity to describe the main functions of a plant in their own way (by using shapes, images, words, etc.). All groups had a good understanding of plant functions and responded positively to their evaluation.

ANALYSIS OF ACTIVITIES

The research rationality led us to apply CHAT framework as an appropriate framework to analyse the activities which took place during our teaching. The use of the CHAT framework enables participants to provide a detailed description of the connections within the lesson, as teacher|researcher and students work together to achieve individual and common goals. The implementation of the CHAT context through teaching in a school classroom supports the concept that the community is continually changing, shaped by the interactions of the subjects. The CHAT model is represented by Engeström (1987) in the form of a triangle, where the subject interacts with the community, rules, division of labor, tools and object (artifact) to reach the outcome This model has become a common framework for representing the understandings based on this theory, as it provides a complete analysis for the structure of a given activity system, or the central activity. However, the third generation of activity theory needs to develop conceptual tools to understand dialogue, multiple perspectives, and networks of interacting activity systems (Engeström, 2001). In this study, the central activity is the educational system, which includes other interacting activity systems and consists of actions.

According to Leontyev (Leontyev, 1981) there is a distinction between activities and actions. Activity (in human beings) is governed by its motive/motives and satisfies a need. Activity is carried out by a community. Actions are governed by their goals and often make sense only in a social context of a shared work activity. Action is carried out by an individual or group. Leontyev argue that:

> Let us now examine the fundamental structure of human activity in the conditions of a collective labour process […] Processes, the object and motive of which do not coincide with one another, we shall call 'actions.' We can say, for example, that the beater's activity is the hunt, and the frightening of game his action. (Leontyev, 1981)

For Engeström (1987) activity is a collective, systemic formation that has a complex mediational structure. An activity system produces actions and is realized by means of actions. However, activity is not reducible to actions. Actions are relatively short-lived and have a temporally clear-cut beginning and end. Activity systems evolve over lengthy periods of socio-historical time, often taking the form of institutions and organizations.

Also, the theorists argue that:

> The theory of activity proposes three levels of interaction between an organism and its environment. At the level of concrete operations, the critical factor in interactions is the external conditions involved in performing

> operations. This level is prominent in the psyches of animals and unconscious operations in humans. The second level is the level of higher primates and humans. At this level the critical factors are the goals of actions and the means of performing the actions. The third level of interaction is the level of the individual personality and the complex social environment. The crucial components here are activity and the individual's motives for engaging in activity. (Grigorenko et al., 1997)

In this context, our central activity of the educational system consists of subjects (students, teachers, educational policy makers, parents), who act on certain objects, which are necessary in order to achieve the desired outcomes of education. The objects include knowledge, skills, values and attitudes students should exhibit that reflect the outcomes. The outcomes of education include the development of individual morally, intellectually, physically, socially and aesthetically. These outcomes are needed by both individual and society. This activity is mediated by tools, such as language, thought, schools, and curricula. The activity is also mediated by the community in which the activity is being carried out. The community provide the rules that regulate the activity and constrain actions and interactions within the activity system. Such rules may be the practices of the educational system and the collaboration between the subjects. Finally, the division of labor refers to the division of tasks between the members of the community, such as the responsibility that subjects share with the community in the activity system.

During the same time, the activity of the educational system interacts with other activity systems and consists of actions. One central interacting activity system is the activity system of teacher training. The improvement of pre- and in-service teachers' training is our main goal of our study, under which we investigated innovative processes and practices in the teaching of living things.

In this context, our innovative teaching of plant processes constitutes an action of the central activity system of the educational system and contains interacting actions that share a common goal. In Figure 7, we represented the interacting actions of the teaching of plant processes and the way they share the common goal. The interacting actions contain the action of teaching the concept of respiration, the action of teaching the concept of photosynthesis and the action of teaching the concept of transpiration. The teaching of plant processes aimed to the understanding of plants as whole entities. The main goal of the teaching was students learning about plants and their processes and the achievement of the outcomes (attitudes and values about life and living things, scientific literacy, motivation to learn science, communication skills). First of all, students learn the parts of a plant and their usefulness. They learn that plants are living organisms and therefore respire and then that plants are photosynthetic, which means that they manufacture their own food molecules using energy obtained from light. Also, students had to learn that plants lose water through the process of transpiration. All these concepts were the basis of understanding plants as living things with dynamic interactive and interdependent processes, and not separate processes. Our innovative approach to teaching, as mentioned in previous pages, followed a specific transformation which fostered the understanding of concepts in an interdependent context.

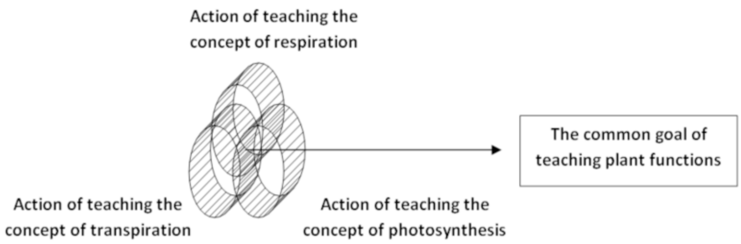

Figure 7. Interacting actions in the teaching of plant processes.

A Model of Achievement: The Goal of Plant Respiration

In this model, there are two interacting actions that are relevant to the teaching of the concept of plant respiration. The action of teaching that humans expel carbon dioxide when breathing out and the action of teaching that plants exhale carbon dioxide are foregrounded as constituting the understanding that plants breathe. These actions are inherently interrelated, in order to facilitate the understanding that plants breathe and absorb free molecules of oxygen (O_2) and use them to create water, carbon dioxide, and energy, which help the plants grow. In both actions, the subjects are the elementary students and the teacher, who interact with the community (school classroom), the rules as a basis for mediation of interactions (how a student collaborates with another student, a student with the teacher, a group with another group, a group with the teacher), and the division of labor (group work). The tools used for the action of teaching that humans expire carbon dioxide when breathing out were language, the body, thought, a worksheet, a glass, water, and a drinking straw. The tools used for the action of teaching that plants exhale carbon dioxide were language, the body, thought, a worksheet, two bottles, water, and celery. Both actions share a common goal, the understanding that plants breathe. The achievement of the common goal was made by the following process: Goal 1 of the first action was the human breath and carbon dioxide. Goal 1 moves from an initial state of an "experiment finding" to a collectively meaningful goal 2 constructed by the pedagogical action (the understanding of presence of carbon dioxide in human breath). Goal 1 of the second action was the plants and carbon dioxide. Also, this goal 1 moves to a collectively meaningful goal 2 constructed by the pedagogical action (the understanding of the presence of carbon dioxide around living plants). Both goals move to potentially shared or jointly constructed goal 3, which is the understanding that plants breathe.

A Model of Achievement: The Goal of Photosynthesis

In this model, there are four interacting actions that are relevant to the teaching of the concept of photosynthesis. The action of teaching that certain foods contain starch, the action of teaching that leaves contain starch, the action of teaching that leaves turn yellow if there is no light, and the action of teaching that yellowed leaves contain no starch are foregrounded as constituting the understanding that plants make their own food. These actions are inherently interrelated, in order to facilitate the understanding that plants make their own food, through photosynthesis, the process a plant uses to combine sunlight, water, and carbon dioxide to produce oxygen and sugar (energy). In all actions, the subjects are the elementary students and the teacher, who interact with the community (school classroom), the rules as a basis for mediation of interactions (how a student collaborates with another student, a student with the teacher, a group with another group, a group with the teacher), and the division of labor (group work). The tools used for the action of teaching that certain foods contain starch were language, thought, a worksheet, bread, potatoes, and iodine. The tools used for the action of teaching that leaves contain starch were language, thought, a worksheet, plant leaves, and iodine. The tools used for the action of teaching that leaves turn yellow if there is no light were language, thought, a worksheet, plants, and aluminum foil. The tools used for the action of teaching that yellowed leaves contain no starch were language, thought, a worksheet, plant leaves, and iodine. All actions share a common goal, the understanding that plants make their own food. The achievement of the common goal was made by the following process: Goal 1 of the first action was the concept "foods and starch." Goal 1 moves from an initial state of an "experiment finding" to a collectively meaningful goal 2 constructed by the pedagogical action (the understanding of the presence of starch in certain foods). Goal 1 of the second action was the concept of "plants and starch." Also, goal 1 moves to a collectively meaningful goal 2 constructed by the pedagogical action (the understanding of presence of starch in plant leaves). Goal 1 of the third action was the concept of "plants and sunlight," which moves from an initial state of an "experiment finding" to a collectively meaningful goal 2 constructed by the pedagogical action (the knowledge that plants need sunlight). Goal 1 of the fourth action was the concept of "absence of sunlight and sunlight." Also, this goal moves to a collectively meaningful goal 2 constructed by the pedagogical action (the knowledge that yellowed leaves – because of the absence of sunlight – contain no starch). All the goals move to potentially shared or jointly constructed goal 3, which is the understanding that plants make their own food.

A Model of Achievement: The Goal of Transpiration

In this model, there are three interacting actions that are relevant to teaching the concept of transpiration. The action of teaching that plants lose water into the atmosphere, the action of teaching that plants lose water through their leaves, and the action of teaching that plants lose water mainly through the lower surface of their leaves are foregrounded as constituting the understanding that plants lose water into the atmosphere. These actions are inherently interrelated, in order to facilitate the understanding that plants lose water to the atmosphere through small openings on the underside of leaves called stomata. In all actions, the subjects are the elementary students and the teacher who interact with the community (school classroom), the rules as a basis for mediation of interactions (how a student collaborates with another student, a student with the teacher, a group with another group, a group with the teacher), and the division of labor (group work). The tools used for the action of teaching that plants lose water into the atmosphere were language, thought, a worksheet, a plant, a transparent bag, and water. The tools used for the action of teaching that plants lose water mainly through their leaves were language, thought, a worksheet, plant leaves, bottles, plant shoots, and water. The tools used for the action of teaching that plants lose water mainly through the lower surface of their leaves were language, thought, a worksheet, plant leaves, water, plant shoots, and vaseline. All actions share a common goal, the understanding that plants lose water into the atmosphere. The achievement of the common goal was made by the following process: Goal 1 of the first action was the concept "plants and loss of water." Goal 1 moves from an initial state of an "experiment finding" to a collectively meaningful goal 2 constructed by the pedagogical action (the knowledge that plants lose water into the atmosphere). Goal 1 of the second action was the concept of "leaves and loss of water." Also, this goal 1 moves to the collectively meaningful goal 2 constructed by the pedagogical action (the knowledge that plants lose water mainly through their leaves). Finally, goal 1 of the third action was the concept of "loss of water and parts of leaves." Also, goal 1 moves from an initial state of an "experiment finding" to a collectively meaningful goal 2 constructed by the pedagogical action (the knowledge that plants lose water mainly through the lower surface of their leaves). All the goals move to potentially shared or jointly constructed goal 3, which is the understanding that plants lose water into the atmosphere.

CONCLUSIONS

The study described in this paper contributes to a limited but growing interest in CHAT-based education research. This research, even though limited, could give impetus to the discussion of cultural studies of science education and, especially, teacher training in applications of the CHAT framework in science education. The experimentation on new processes in natural science pedagogical actions in the wider systems of activities demonstrates the importance of CHAT for science education and encourages us to study this research field. We believe that this field could yield new and useful insights into formal and informal science education.

The results of this analysis provided many answers, but also raised new research questions. For example, our analysis has been used to examine the actions of teaching through helping students in elementary school learn about "plant functions." The interactive activity systems described in this study capture a moment in time of the learning process. The components of the CHAT triangle (community, subjects, etc.) are constantly changing as students evolve their thinking, explore new options, and interact with other activity systems. These issues should be further explored in order for CHAT to become better understood in educational research. Through this process, CHAT-based research and analysis should lead us to new forms of learning, knowing, and interacting.

Nevertheless, the results make us very optimistic about the implementation of a CHAT framework in biology education in elementary schools. Students participated actively in all educational activities and successfully achieved the object of the main activity system of teaching plant functions, as well the objects of the sub-activity systems. Also, students developed positive attitudes and values about living things and reinforced their creativity and communication skills through collaborative work. Doubtless, using CHAT in science education about living things seems promising. It might be a way to fulfill the main objectives of science education, which are the motivation of students to experience meaningful learning, the achievement of scientific literacy, and the adoption of social attitudes and values.

APPENDIX I

Plant functions: Worksheet A (Group ...)

When you blow into the glass containing limewater…

Words to use: Carbon dioxide, expire, inhale, oxygen, cloudy

You fill two bottles with limewater (place one stalk of celery in the first bottle) …

Words to use: respiration, oxygen, carbon dioxide

When you add iodine …

Words to use: starch, bread, potatoes, color

When you add iodine …

Words to use: discolored leaf, starch

You covered some leaves with aluminum foil …

Words to use: observe, color, yellow, light

The leaves you had covered with foil …

Words to use: discolored leaf, iodine, light

You covered a plant in a pot with a transparent bag …

Words to use: water, light, drops

You filled two identical bottles with water …

Words to use: oil, light, stem, leaves, water level

You put similar stems of a plant in four different bottles …

Words to use: light, oil, stems, leaves, Vaseline, upper surface, lower surface, water level

APPENDIX II

Plant Parts and Their Processes: Worksheet B (Group …)

Describe the main plant processes. You can use shapes, images, words, etc. See pictures below.

APPENDIX III

Plant pro: Worksheet C (Group ...)

A. Mary is home again after summer holidays. She opened the door of her room and went inside. Immediately she opened the shutters to get light into the room. She was very surprised when she saw that her favorite basil had wilted. But how did it happen? My grandfather watered it every day, thought Mary. Without wasting any time, she found her school textbook, which talked about plants. In one chapter, she found the plant experiments they had done in school. Unfortunately, the conclusions were missing. Can you help Mary understand what had happened to her basil?

B. Mike went on vacation for a few days and left this note to his friend Eva.
Do you agree with the advice? Is it enough?

> *Dear Eva,*
> *please take care of my dog and my plants:*
> *Put enough food and water for my dog.*
> *Keep the shutters open.*
> *Water the plants.*
>
> *Best wishes,*
> *Mike*

C. “Respiration and photosynthesis are opposite processes.” Can you explain this statement?

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