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DEVELOPMENT OF COGNITIVE CONDUCTS DURING A COMPUTER SIMULATED ENVIRONMENTAL ANALYSIS

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ABSTRACT: This paper points out that acid rain is an environmental problem that usually occurs in regions close to carboelectric complexes. A possible solution to this anthropogenic problem requires elements that go beyond the domain of physico-chemical knowledge. Therefore, we consider that it is necessary to approach this problem from an interdisciplinary perspective. Thus, the aim of this research was to demonstrate the attitudes that some individuals, put into practice in the analysis and solution of a computer-simulated environmental problem. The method employed was the case study and it counted on 8 participants aged between 14 and 17 years old. Data were obtained through systematic observation, clinical interviews and log files. Data interpretation aimed to evince the development of cognitive conducts in the environmental analysis. Thus the existence of different behavior profiles related to environment were verified: individuals oriented by economical notions; individuals oriented by Law principles and those guided by models of the natural science's descriptions and explanations. [*Chem. Educ. Res. Pract.*: 2004, 5, 157-174]

KEY WORDS: *cognitive development; educational software; problem solving; acid rain*

NOTE: This paper has been translated from Portuguese by *Salete Moncay Cechin*.

INTRODUCTION

Ecological crisis comprises a large number of aspects such as the biosphere devastation, changes in the atmosphere's chemical composition, global weather change, demographic explosion, dumping in rivers, damage to underground water, deforestation, endangerment of species, and ecosystem imbalance (Hösle, 1992). Nevertheless, this crisis frame is undoubtedly related to human actions, since no other biological species has destroyed so many other species and modified so badly the biological balance of the planet as humankind has done (Müller, 1996). Thus, the discussion about the ecological crisis should be done from the human achievements approach.

According to Vittorio Hösle's (1992) philosophical analysis, the irrefutable and highly emancipative character of natural sciences and modern technology achievements cannot be dissociated from the detaching and old-fashioned concept of nature adopted by the humanity. Thus, there are ethical requirements that result from this crisis. These ethical requirements could open a path towards a new ethical-political paradigm for humanity's future. In the

search for ethic, questions like “What should we do?” or “Which tendencies should we adopt?” seem to be relevant. The answers for these questions are important to build juridical and economical proposals to face the environmental depletion and degeneration. Finally, Hösle presents ecological crisis as a call for a change of paradigm (the ecological paradigm).

The new paradigm has changed the concept of nature. This concept is dynamic and has its own history and evolution. A study on the history of the concept of nature was made by Hans Jonas (1985). In the course of civilization’s development, independently of the religious aegis, humankind assumed that their actions, regardless of the place and of the extension they had, would not substantially affect the course of nature. However much humankind caught and controlled animal species and dominated the forces of nature, however much they extracted natural resources, humankind have always believed that nature would remain intact in its sovereignty and power. On the other hand, humankind was subjugated by nature’s cycles and laws, as evidenced, for instance, by the inclemency of weather and the earth’s tectonics. This submission of humankind to nature maybe happened up to the modern period. In contrast, nowadays one should consider that human actions, powered by the technology, may seriously and irreversibly harm nature and humankind itself (Giacoia Jr., 1996). In this manner, the new paradigm has the idea of humankind’s responsibility for the nature and for the future of next generations on Earth (Jonas, 1985).

Change in paradigm always implies a balance between rupture and continuity. The question that rises is how to meet this balance. According to Hösle (1992), a non-retrograde ecological criticism of industrial society should neither deny the advances of modern natural sciences and technology, nor the dynamism of economy and market selfishness. Besides, according to Jonas (1985), there is a need for a normative regulation (meaning law and, in a lower extend, economy) on the potential of human actions. Nevertheless, these regulations, above all, depend on the knowledge formulated by environmental sciences. Thus, sciences have the duty both to detect and analyze the causal nexus which unleashes the ecological crisis, and to study the measures that could be taken to face it; and this task is essentially an inter- and transdisciplinary issue (Müller, 1996).

In this sense, environmental pollution, which constitutes the reference for the study here presented, and on which the computer simulation used in this research is based, does not concern only environmental chemistry. Perceiving it from this narrow perspective would be reductionism, resulting in a distorted way of investigating this problem. Environmental pollution is, or should be, a matter of concern of all knowledge fields related to it, such as education, communication, economy, law, biology, engineering, and meteorology.

Regarding the professional practice in environmental analysis, according to Fowler & Aguiar (1995), the analyst’s difficulties in incorporating all of the factors that could influence their analysis are:

1. correlating all the components of a system;
2. foreseeing interactions among minor problems;
3. exclusion of aspects that the analyst considers irrelevant or that are beyond their expertise field;
4. lack of consideration for the weakness of the theory premises that are reference to their work or not paying enough attention to the statistic sample problem;
5. exclusion of subjective aspects, classifying them as unimportant, aiming at simplifying the analysis.

However, cognitive conducts and values are not always rationalized. In environmental issues usually the reason for a behavior is not known. Things are done because they are good or because they are better (Winter, 1995). Generally, attitudes and thoughts are not explained

based on a determined system of concepts or on another knowledge domain. Even though informative sketches are sometimes associated to one or another environmental comprehensive system, (e.g., juridical, economical, physico-chemical, and ecological systems), an effective elaboration of them is not reached.

On the other hand, a better understanding of environmental comprehensive systems could favor the emergence of values related to environmental or ecological ethics. In this sense, studies aimed to analyze learners' cognitive procedures, the strategies they adopt when carrying out an analysis, and the comprehensive systems reported by them, can be useful to propose and develop educational activities focused on environmental issues.

There is an increasing use of educational activities with different pedagogical purposes which focus on environmental issues. Such educational activities encompass different topics, among them: environmental ethics and economical management of waste (Institute for Environmental Education, EUA, 1994), water pollution (Whisnant, 1984; Whisnant & McCormick, 1992), the use of pesticides in agriculture (Taack, 1994), spillage of oil in the oceans (Hampton, 1993), and the ecosystem of forests in cold regions (Kankaanrinta, 1991). Additionally, different teaching strategies can be used when working with environmental issues, such as the use of maquettes (Taylor, 1985), computer software programs (Whisnant, 1984; Kankaanrinta, 1991; Farynaiarz & Lockwood, 1992; Whisnant & McCormick, 1992), paper-and-pencil exercises (Furió, Iturbe, & Reyes, 1995), and role playing games (Whisnant, 1992; Duveen & Solomon, 1994).

In this sense, there are studies about the learning and development of concepts related to environmental sciences, such as water quality (Agelidou, Balafoutas, & Flogaitis, 2000) and air pollution (Wylie et al., 1998). Some of these studies even employ computer software programs (Wylie, McGuinness, & Orchard, 2000).

The study of cognitive conducts presented by individuals during the environmental analysis of a computer-simulated air pollution problem can be interesting from a psychological and educational point of view. In this sense, the specific objectives of our study were to understand: 1) the individuals' representations of the proposed problem; 2) the chaining of their procedures aiming at solving the problem; 3) the conceptual development during the problem solving. Thus, this research was more concerned on demonstrating kinds of reasoning employed by the individuals when solving the problem than concerned on evaluating whether their reasoning was correct or not.

Research Setting

In the early 90's, the press in the south of Brazil reported that acid rain found in northeastern Uruguay, which affected the local mixed-farming production, was due to coal burning in a Brazilian thermoelectric station located in Candiota, south of Rio Grande do Sul State. It was said that this event was threatening the Brazil-Uruguay bilateral relationship, making things hard for the emergent MERCOSUR¹ integration. News reports published that, even if Uruguayan analyses were not clear, it would be easy to detect the source of acid rain and solve the problem through a technical solution.

Nevertheless, in the late 90s² the problem in Candiota was not solved yet. A research carried out in Brazilian and Uruguayan newspapers found out some news reports about this matter.

¹ South Cone Common Market, which includes the South American countries of Argentina, Brazil, Chile, Paraguay, and Uruguay.

² At the time when the educational software used in this research was being developed.

In 1996, the Uruguayan family de Melo, who lives about 49 miles from southeast of Candiota, still suffered from health problems. It was also reported that respiratory infections and the incidence of lung cancer had increased.

In 1997, the acid rain problem had not been solved yet, maybe because it was a seasonal problem. Due to the fact that it is related to the winds regime, the problem is intensified in summer, when northeastern winds blow towards the Uruguayan territory. However, in the same year, the Brazilian government celebrated the prospect of expanding the carboelectric complex in Rio Grande do Sul through privatization. On this occasion, the chairman of CEEE – Companhia de Energia Elétrica/RS (Power Supply Company of the State of Rio Grande do Sul) rejected the “controversies concerning the accusation of acid rain in Uruguay”, and assured that “there were papers signed by Uruguayan authorities and countersigned by international organizations proving the inexistence of the problem”.

With this real problem in mind, educational software based on the pedagogical strategy of problem solving was developed. This software is described in the topic entitled “The task”, in the “Methodology” section of this paper.

METHODOLOGY

The essence of psychological development is change; however, determining how change occurs is very difficult. Studies that examine changes when they happen suggest ideas about the mechanism that produces them and the conditions under which they are more frequent (Siegler & Crowley, 1991). This is one of the situations when a case study is recommended (Moro, 2000).

In this particular aspect, a research strategy fit to understand the change process is the microgenetic analysis (Siegler & Crowley, 1991), which is indispensable to someone who intends to capture the process of cognitive elaboration (Moro, 2000). In this sense, a fundamental problem is to clarify the relationship between systems of understanding and procedures of discovery, that is, between the nature of the individual’s intervention control and their knowledge (Mosca, Silveira & Burigo, 1993).

Microgenesis departs from the hypothesis that the initial knowledge activated by the individual who is at the start of a problem solving is not yet updated or specified (Saada-Robert, 1992). This knowledge is syncretic, that is, it is an artificial fusion of thoughts from disparate origins, since an overall view is still confused. This fusion can be seen as a combination of two elements: one of diffuse generality, associated to the present situation, and another of juxtaposition of particularities, associated to previous knowledge on which the individual is based on. From this global and indistinct understanding emerge objects that are distinctly understood, and that are progressively changed into a precise and synthetic knowledge. Thus, microgenetic construction consists of a double way road from the diffused and disparate to the precise and unitary knowledge.

This initial interpretation of reality is originated from the individual’s natural epistemology. According to Inhelder and Caprona (1992), this natural epistemology originates a world vision focused on the understanding of reality or of oneself as a thinking being. The activated knowledge is essentially a particular knowledge, and the ways they are used are strongly individualized. That is the reason why microgenesis is concerned with specific knowledges of a particular psychological individual who is involved in the solution of a given problem.

The concern of the studies on a particular psychological individual is to reveal the dynamics of individual’s conducts, evaluations, intentions and values, the way and means individuals choose, as well as the individual’s particular heuristics which, through different paths, can lead to the same results. The aim is to be able to distinguish the general

characteristics of the process or the organized and finalized chaining of actions. Thus, an approach of the temporal organization of conduct in specific contexts is possible. It means studying the order of individuals' chaining of actions and operations that favor the interference of the anticipation processes when these individuals apply their structures to understand the problems that are in the course of their activity.

The study of those processes demands experimental tasks that enable apprehending the development of the individuals' thought through their actions. Thus, experimental tasks should favor individuals' attention, challenging them to solve the problem. The tasks should also enable free manipulation of materials, exploration of contents and processes of creation. On the other hand, in order to not interrupt or deviate the spontaneous development of the conducts, the experimenter should minimize his/her interventions (Inhelder, Ackermann-Valladão, Blanchet, Karmiloff-Smith, Kilcher-Hagedorn, Montangero & Robert, 1976). However, the inquisitive feature of this method depends on the task given to the individuals and of the type of analysis the experimenter intends.

The development of a research with such characteristics needs experimental tasks that have physical manipulation and a target goal (Mosca, Silveira & Burigo, 1993). In this sense, physical manipulation can reveal the individual's thought. Complementarily, the target goal to be achieved in the task enables to reveal both the solution the individual has proposed to the problem and the explanation given to it. However, experimental tasks do not necessarily have to be natural, quotidian or real because the research participants may either be too used to them or too distant from the subject matters under study (Lawson, 1983), and it would make the research inaccurate (White, 1997). Sometimes artificial or simulated tasks are more appropriate, as long as they are neither physically impossible nor too different from a similar real activity (Lawson, 1983; White, 1997). For instance, in the environmental analysis field, real situations are sometimes very complex and require several specialized knowledge. Besides, they also demand considerable time and cost to be finished. Thus, alternatives should be found in order to develop the goals of the research.

Among the available alternatives, maybe those which involve computers to develop educational simulations are the richest ones. Among other features, educational simulations enable a realistic environment. In this environment, the individual is presented to a simplified problem and needs to take and put into practice a series of decisions aiming at the solution of the problem. In this sense, simulations enable the individual to verify how a simplified model of reality works when applying their own hypothesis. This allows the researcher to "shed light" on the reasoning in real life situations (Lawson, 1983). Thus, we believe that educational simulations can be employed to study cognitive conducts focusing on the environmental analysis.

The task

In this research the task employed was the Carbopolis software³ (Eichler et al., 1998). The problem presented by Carbopolis consists of the decrease of a mixed-farming production in a place next to a thermoelectric station. In order to solve this problem, the student can verify the caused damage, the source of this damage, and propose a solution that could minimize or eliminate the problem (Eichler & Del Pino, 2000).

The software is based on data from a study about the polluting potential of the thermoelectric station in Candiota, Rio Grande do Sul State - Brazil. That research made it clear that the emission control measures and legal requirements were inadequate or

³ Carbopolis is a freeware. Spanish and Portuguese versions available at www.iq.ufrgs.br/aeq/carbop.htm.

insufficient to avoid the environmental contamination (Fiedler, Martins & Solari, 1990; Fiedler & Solari, 1991).

The causal nexus of this environmental problem – or of the real-life situation on which the computer simulation is based – can be described as follows: in the thermoelectric station of Candiota, coal burning containing sulphur rates above the recommended, between 3.5 and 5% (in Carbopolis this rate is of 6%), has produced a large amount of sulphur dioxide, a highly reactive gas that is considered an air pollutant. Sulphur dioxide was dispersed in the atmosphere through the action of the winds towards northeastern Uruguay (in Carbopolis, towards a mixed-farming region). The air humidity and the rainwater reacted with the pollutant gas and resulted in acid rain precipitation. This acid rain damaged grasslands and rice plantations (in Carbopolis, soya plantations) and probably caused respiratory and digestive problems in animals.

Aiming at solving the problem of this simulated situation, the software contains (Eichler & Del Pino, 2000):

- a map to help to geographically situate the presented problem;
- characters who describe the problem;
- menu and icons enabling collection of air and rainwater samples from the map; analysis of the samples, and installation of antipollution equipments;
- hypertext tool with 56 topics and more than 250 active links;
- word pad tool to register partial conclusions and the result of the analysis of the samples;
- two questionnaires to help on the conclusion of the activities proposed by the software.

Figure 1 shows a screen shot of Carbopolis.

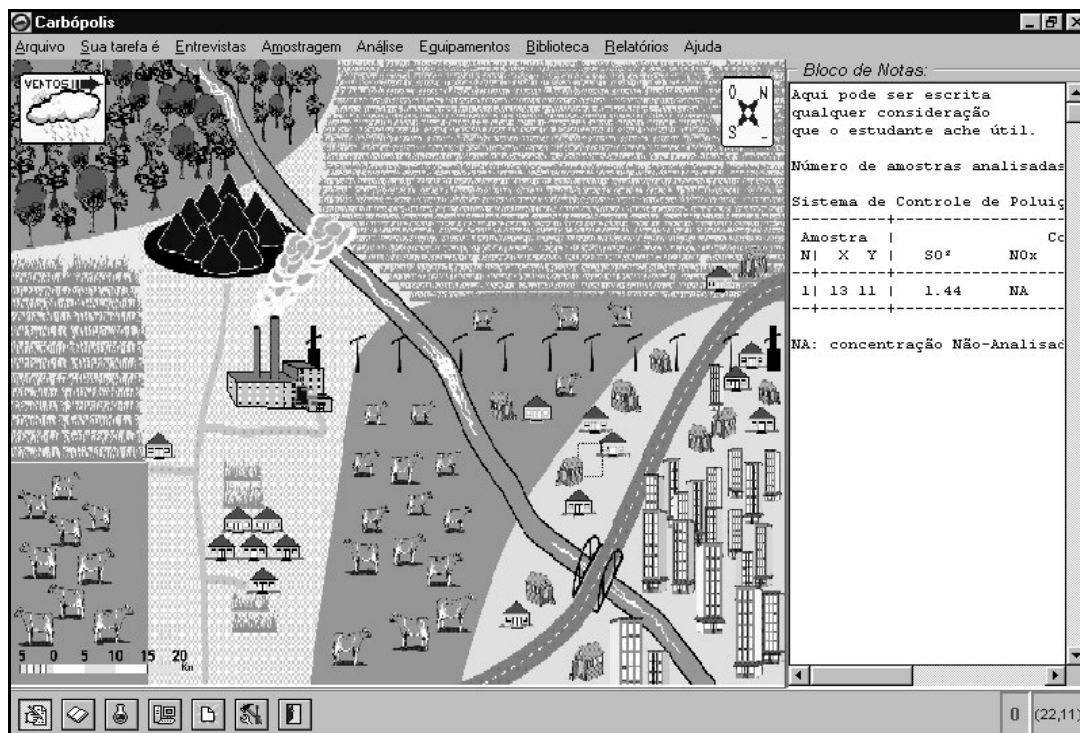


FIGURE 1. Screen shot of the Carbopolis software.

Data collection and analysis

With regard to the analysis of cognitive conducts, there are some requirements related to the data collection that should be observed. In this sense, the meanings of actions and operations can just be pointed out by the association of indications manifested during the research. Thus, there is a need to register all the development of an action (Mosca, Silveira & Burigo, 1993). In this sense, when the work involves educational simulation, as done in this research, log files can be used for this purpose. Log files keep track of the amount of time spent by the individual who uses a computer environment in each navigation choice (Barab, Bowdish & Lawless, 1997). These log files are individual, integrated, continued, and they are usually part of the simulation environment.

From a case study outline (Siegler & Crowley, 1991), the analysis of learners' cognitive conducts was carried out with the contribution of 8 participants aged between 14 and 17 years old. The research participants used the software in sessions of 45 minutes, and there were as many sessions as needed for the solution of the proposed problem by the participants. During the solution of the task, systematic observations and clinical method were applied to observe the progress of the procedures employed to reelaborate the causal nexus, that is, the procedures the research participants used to solve the task.

Interferences of the examiner who observed the process were limited. In this sense, the following topics guided the examiners:

1. When the participants had geographically localized the problem, the examiner would ask *why the problem was located there; how the participant had reached that conclusion; what was the explanation for the problem, and how they could solve it.*
2. When a participant had identified a possible cause for the problem, the examiner would ask *why the participant attributed this cause; how they had reached such a conclusion; how could they guarantee that it was the cause of the problem; what was the explanation for it, and what could be done to solve the problem.*
3. Finally, when the participants had solved the problem, the examiner would ask *how the participant had reached that conclusion; how they could explain it, and if the problem presented to them could exist in the real world.*

The interviews were recorded on audiotape and later transcribed. The analysis of each case was carried out under the Piagetian research tradition (Inhelder & Cell erier, 1992). Data included: log files of the software, texts written by the participants while using the software (word pad and records), and audiotapes transcriptions. The data were assembled in protocols (Stake, 1994), and later on they were used for analysis. The log files and the texts written by the participants enabled a description of how the participants' discoveries relating to the environmental problem were developed. The audiotapes transcriptions, as well as the log files and the written texts, were useful to describe the cognitive conducts of the research participants in the problem-solving task.

RESULTS AND DISCUSSION

In this section, some cognitive conducts involved in the environmental problem-solving are described. The presentation of the cognitive conducts come along with a theorization of the discovery strategies, proposed by Inhelder & Caprona (1992), whose elements were discussed in the section about the microgenetic analysis ("Methodology" section).

Although Inhelder and Caprona (1992) developed conclusions on the whole set of their experiments⁴ on the cognitive conducts in the development of infant's discoveries, there is not an agreement about a way of presenting collected data of different studies. Two other papers (Blanchet, 1992; Saada-Robert, 1992) present different models for the description and interpretation of the collected data. Although in a previous study (Eichler & Fagundes, 2000) we presented the analysis accordingly with the model suggested by Saada-Robert (1992), in the present study we adopted the model suggested by Blanchet (1992).

The results of Blanchet's research (1992) are described through examples extracted from an analysis of a group of 27 children aged between 7 and 12 years old. The examples presented by Blanchet aim at illustrating the theoretical definitions previously presented in his research. Blanchet's examples are quite similar to those used by the Piagetian research tradition, consisting of extracts of clinical interviews protocols. However, Blanchet's extracts have more emphasis on the description of actions, and contemplate a significant amount of interpretation of the described actions. The extracts of clinical interviews protocols are commented in a series of digressions that reiterate and reaffirm what Blanchet had previously said in his study, not as a hypothesis, but as an assertion. In other words, Blanchet's description of actions is replete with theory.

Next, different cases are presented in order to represent the development of the individuals' discoveries in the environmental analysis.

The initial representation of the proposed problem

Two kinds of responses were verified: 1) responses related to clear representations of the problem; 2) responses driven by imprecise representations. In the second case, such responses were related to prior ideas the research participants had about the causal relations of the aspects involved in the task (Park & Pak, 1997).

The problem solving using environmental analysis started with the determination of a hypothesis which involved the identification and understanding of the pictures on the map (Figure 1). Since the pictures on the map suggested meanings, the first hypotheses were clearly related to them. For instance, when some research participants noticed that the thermoelectric station operated with water, they understood that:

Mathias (aged 15): *"The river is causing the problem; it is taking the pollution to the town."*

Besides, based on real-life situations related to pollution, a research participant thought that the problems were related to:

Carolina (aged 14): *"The pollution of the cars in the town"*.

Therefore, after decoupling the elements that composed the map, the participants took a step further in the analysis and attributed appropriate meanings for the pictures on the map, associating them to the proposed problem. This process consisted of questions like:

Lia (aged 17): *"What is this yellow thing here? Does it represent a road? Is the wheat field [it was a soya field!] here?"*

On the other hand, Paulo (aged 14) integrated the observable objects, attributing the source of the problem to the air pollution and to the thermoelectric station. According to his statement,

⁴ These experiments comprise 16 different tasks in which 601 individuals aged between 3 and 14 years-old have participated.

the observation was due to a prior knowledge about causes and effects of environmental problems:

Paulo: *“I’ve heard about several environmental problems, but I’m not sure about this one.”*

However, regarding the environmental analysis, even when the initial hypothesis was consolidated, it was still either strict and objective or wide and divergent. An example of the latter is:

Carolina (extract from her note pad): *“It is wrong to place a station next to a farm, to a river, to a reserve or to a town because it will affect the population. It’s also wrong a coal mine next to a reserve, to a river, to a farm and to a town. The station will leave chemical residues and these residues may flow into the river and pollute it. It can cause diseases in the population in the town and also cause diseases in the animals that live there.”*

In this sense, Carolina presented a special concern about environmental issues and also a typical environmentalist behavior. However, facing a problem that required an objective approach, she represented it in a wider way than the problem could suggest.

There were also research participants who did not have an initial representation well consolidated. Piter (aged 15), for instance, maybe formulating a draft hypothesis, centered his initial actions on the center of the map, but he did not attribute any initial connection to it. He would just do so after collecting and analyzing the first samples. Then, he finally distinguished the several meanings related to the regions on the map.

Procedures chaining

In general, the analysis of water and rainwater samples was the way the research participants found to confirm their hypothesis. For example, before Piter had not found out the sequence **sample** → **analysis** (although this sequence is somewhat related to the knowledge about the software tools and the simulation functions), he did not proceed in identifying the problem he was trying to solve. Thus, the investigation of a hypothesis does not proceed before the sequence **sample** → **analysis** is recognized. One piece of evidence of an analytical method insight could be illustrated by:

Lia (after reading the topics of the program’s library): *“How will I get this thing in order to analyze the gas that is coming from the factory? What do I do to take this stuff from here to there?”*

(referring to the pictures of the sampling tube in the topics): *“Will I have to find it out too?”*

The research participants planned their actions as they understood the steps of problem-solving process. That is, the concepts related to the causes and effects of the proposed problem and the procedures to solve it (e.g., sample and analysis; identification of the problem, and installation of efficient antipollution equipment).

In the course of participants’ actions, new aspects emerged. For example, when Lia was reading the topic about the characterization of air pollutants, she raised a question about the choice of an analysis standard:

Lia: *“Sulphur is a gas which is present in coal and oil. How can we measure it?”*

However, the selection of new aspects was not at random; the aspects were selected because they were integrated with previous representations. “Initially, individuals try to explain a

phenomenon through an implicit general theory, with which they stick with until generalizing it.” (Inhelder & Caprona, 1992, p. 47). Thus, once unexpected facts or information emerged, research participants created other representations which differ from those with which they were working with. So, successful or failed actions led the participants to conceptually restructure the problem they were operating. However, “a common phenomenon is the inadequacy of the scheme adopted initially, which becomes an obstacle for the problem solving” (Inhelder & Caprona, 1992, p. 72). In this case, the reorientation of ongoing procedures implies the understanding of such obstacle. Thus, the initial hypothesis about the causal nexus of the problem and about the procedures to be developed in order to solve the problem were progressively refined and put to test. Consequently, research participants’ successes and failures helped to orientate their progress.

Procedures that revealed the success, the failure, the hypothesis and its reorientations were, among others: the placement of sampling tubes on the map that represents Carbopolis region, and the parameters used in the analysis of the collected samples. Although there are symbolic implications in the problem, the spatial support is part of the problem solving, since “the individual should have references to situate the elements that are necessary for the problem solving” (Inhelder & Caprona, 1992, pp. 64-65). In this sense, the relationship between the interpretation of the pictures on the map and the location, distribution and orientation of the effects connected to the environmental problem became evident. The location could be done based on the interviews with the locals of Carbopolis region or through the installation of sampling tubes before the analysis of the air pollutants. With regard to this, there was also the need to differentiate the direction of the winds that spread the pollution over the region. Thus, the procedure of distributing sampling tubes was useful to learn the hypothesis formulated by the research participants when they were exploring the problem. The following descriptions illustrate this procedure, and can be better understood taking Figure 1 as reference.

Alexandre (aged 14) and Paulo worked with a very objective causal hypothesis related to the thermoelectric station (at the center left of the map). Alexandre, based on his hypothesis, installed a sampling tube directly on the thermoelectric station. On the other hand, Paulo installed two sampling tubes, one on the thermoelectric station and another one on the farm that presented problems on the soya fields (at top to right of the map). Afterwards, in order to confirm his hypothesis, Paulo installed a sampling tube on the right side of the thermoelectric station, in a region that did not present any pollution problem because the winds did not blow in that direction (from right to left on the map).

At the beginning, some research participants randomly distributed the sampling tubes on the map. The distribution of the sampling tubes just became systematic after the discovery of new aspects. That is, participants started to place the sampling tubes in representative regions – next to the farms, the towns, the forest reserve, the thermoelectric station and the coal mine. Before this procedure was consolidated, Claudio, for instance, placed and removed the sampling tube many times. Additionally, at the beginning of the second session, he did not seem to distribute the sampling tubes accordingly to his hypothesis and to the geographic location of the problem. The distribution just stopped being random and became consistent with his hypothesis when he identified where the problem was. Then, Paulo decided to distribute a sampling tube for each region in order to compare the data from regions where the locals had reported some problem, with those from regions where there were no problems reported.

In short, in the course of this research, two distinct behaviors were observed. In one of them, the individual formulates a hypothesis about the problem and then, departing from this hypothesis, he applies strategies and procedures to the given problem. In the other behavior,

the individual interprets the characteristics presented by the environment and constructs new procedure systems.

There are a number of studies that also provide evidence of two existing controls in individuals' cognitive system. These two controls have been revealed in different contexts and can be named, respectively, *top-down* and *bottom-up* (Beasley & Waugh, 1997; Jacques & Fagundes, 1999); *forward* (from prediction to consequence) and *backward* (from consequence to prediction) *inferences* (Bindra, Clarke & Shultz, 1980), or *controls based on ideas* and *on experience* (Park & Pak, 1997).

Tables 1 and 2 show examples of cognitive controls used in the three steps of the task, that is, the initial representation of the proposed problem, the collection and analysis of air samples, and the proposition of a solution to the problem. These tables are based on protocols and illustrate research participants' actions, excerpts of their statements, and a summary of their proceedings.

TABLE 1. *Examples of top-down cognitive control.*

<i>Initial representation of the proposed problem</i>		
Previous action	Research participants' statements	Proceedings
Reading of the opening text of the computer software program	[Paulo]: <i>I've heard about several environmental problems, but I'm not sure about this one.</i>	He recognizes different regions on the map, relating regions to their names.
<i>Collection and analysis of air samples</i>		
Reading the information about the thermoelectric station	[Paulo]: <i>Well, I think that (...) it is the high level of sulphur (...) dioxide that causes problems to the cattle and to the plantation.</i>	He places three sampling tubes on the map: in the station and in the two farms where the problem is present.
<i>Solution of the problem</i>		
Analysis of the collected samples	[Cláudio]: <i>I'm not sure; perhaps there is a way of treating this sulphur or even a way of stopping it.</i>	He installs the desulphurization equipment and analyzes again the levels of sulphur dioxide.

TABLE 2. *Examples of bottom-up cognitive control.*

<i>Initial representation of the proposed problem</i>		
Previous action	Research participants' statements	Proceedings
Reading of the opening text of the computer software program	[Lia]: <i>What is this yellow thing? Does it represent a road?</i>	She moves the mouse randomly over the computer screen.
<i>Collection and analysis of air samples</i>		
Reading of hypertext topics	[Lia]: <i>I don't know what kind of chemicals they are using in the factory. (...). We have to analyze everything: the water, everything. Even the soil have to be analyzed.</i>	First, she looks for the item "Analysis" in the program menu. Next, she verifies the need of an analysis. She proceeds with the analysis of the parameters following the sequence of the menu.
<i>Solution of the problem</i>		
Analysis of the collected samples	[Piter]: <i>We have to analyze all the samples, don't we? We have to place one by one.</i>	He installs all the antipollution equipments, one by one. Next, he verifies how effective they are through the analysis of the sulphur dioxide.

Conceptual development

With regard to the concepts or, in this case, to the understanding of the causal problem, an insight towards objectivity is gradual, but certainly offers resistance. Initially, for example, Carolina's hypothesis was related to the pollution of the rivers. However, when she was asked about the flow direction of the river, her answer pointed out that her scheme was not shaken:

Carolina: *"It [the river] comes from the forest [above on the map] and flows down. So, it passes by the thermoelectric station [center left of the map] and brings some of it [the pollution] to the town [below the center] and to the farm [above the center]"*.

It would mean that the pollutant was dispersed on the river counterflow. She took a while to understand the inconsistency of her hypothesis, and it was not before understanding so that Carolina could get to a more objective causative construction in relation to the problem solving.

The choice of an analysis parameter and its justification also revealed the causal hypothesis the research participants had formulated to the problem solving. Next, an extract that reveals the formulation of a causal hypothesis related to the analysis is presented:

Interviewer (I): *"Why do you want to analyze the gas that comes from the factory?"*

Lia: *"Because I don't know what kind of chemical elements they use in the factory. I don't know what comes from there. It's possible that it is causing damage to the cattle and to the local vegetation. It's necessary to analyze everything. The water, everything, even the soil has to be analyzed."*

Later on, Lia confirmed again her idea, already having clearer parameters to analyze. Lia's hypothesis was still being objectified:

Lia: *I have to analyze that smoke, because it has sulphur: 80%*

[although, it was not possible to understand if she was referring to a percentage quantification of her certainty about the fact or if she was referring to the sulphur concentration in the smoke of the factory]". After confirming the presence of sulphur dioxide in the smoke from the thermoelectric station, she was thinking about developing a strategy to verify the possible presence of another pollutant that, together with the sulphur dioxide, could be causing the observed effects:

Lia: *"I have to find a way of collecting a sample of air to know if there is another kind of pollutant there."*

The chosen analysis parameter (particle material, hydrocarbons, carbon monoxide, photochemical oxidants, sulphur dioxide or rainwater pH) also could indicate two cognitive controls used by the participants: a cognitive control directed by a hypothesis and another one directed by the elaboration of contingent facts. Paulo, for instance, employed a single causal hypothesis, always using the procedure of analyzing the sulphur dioxide. On the contrary, Piter revealed, at the beginning, an action of exploration, carrying out the analysis of all sort of air pollutants. However, this initial conduct changed in the problem-solving phase, when Piter's analysis was related to evaluating the efficiency of the different antipollution equipment installed in the thermoelectric station. On the other hand, Piter had progress in the causal sequence. At the beginning of this phase, Piter still proceeded with the analysis of the

rainwater pH. However, when he was certain that the decrease in pH rate was due to the concentration of air pollutants, he stopped with the analysis of the rainwater pH and looked for the pollutant that was causing this decrease. Later on, when he was certain that the sulphur dioxide was the cause of such pollution decrease, he proceeded with the analysis of the rainwater pH.

In spite of the success achieved, both the justification for using the procedure, and the causal explanation given to the problem were inconsistent. In this sense, Alexandre, who quickly solved the problem, did not attribute to the problem the relation of conservation and transformation of the substances that were related to the causal nexus of the problem. Maybe it happened because he either did not pay enough attention when exploring the program, or due to excessive confidence in his beliefs. When Alexandre had just started using the program, as he recognized the pictures on the map and identified the thermoelectric station, he developed an idea that the acid rain was the causal factor. Afterwards, he reported that he had read about it and already knew that kind of environmental problem.

In the short time of using the program, and maybe because of this, Alexandre presented conceptual confusion related to the chemical system:

Alexandre: *“Before the thermoelectric station [its special location in relation to the winds direction] the rain was normal, right? The pH was not acid.”*

I: *“What caused the pH to become more acid?”*

Alexandre: *“It could be the sulphur hydroxide (sic)”*.

I: *“Why does it cause the pH to become more acid?”*

Alexandre: *“The reaction that happens.”*

Even after solving the problem, Alexandre continued to manifest, in part, the same kind of Confusion when explaining how he had found the solution:

I: *“In your opinion, have you solved the problem?”*

Alexandre: *“No, No... I lowered it... Ah! How do you say that? ...to much more tolerable levels.”*

I: *“Levels more tolerable of what?”*

Alexandre: *“More tolerable levels of... [pause] water acidity and of the [pause] sulphur [pause] monoxide (sic)”*.

I: *“And do you think it will solve the problem?”*

Alexandre: *“Yes, but in a medium term”*.

The pH scale indicates acidity; therefore, it is not the scale itself that becomes acid, but the thing that it measures. Alexandre also confused the sulphur dioxide with other presumed chemical compounds which he denominated “*sulphur monoxide*” and “*sulphur hydroxide*”. Furthermore, in a certain moment of the interview, Alexandre situated the sulphur dioxide in coal. In this manner, Alexandre did not present the solution with the required knowledge about the systematization involved and just scratched the surface of the problem. Alexandre could have solved the problem properly if the software had a control function, but it was not intended to have such feature (Eichler & Del Pino, 2000).

The excerpts above reveal some difficulties related to the language. This matter falls into the domain of the sign science, the semiotics. These semiotic aspects can be presented in relation to the formation of symbols: “in strict sense, representations embody (...) two complementary aspects: semioticity and possibility of individuals’ reflection on objectives and means. These aspects define the essentially instrumental function of the representation. (...) The two aspects of the representation are complementary and inseparable: they

contribute to form cognitive instruments that become to the individual ‘objects that help them to think’.” (Inhelder & Caprona, 1992, p. 34).

Language is a representation that helps to think. It is not surprising that, in the chemistry field, this notion alludes to the attributed founder of chemistry: “Lavoisier had a strong interest on nomenclature and language. Before him, chemistry and language were not a harmonious pair: it was commonplace for philosophers to lament on the way chemists expressed themselves” (Laszlo, 1995, p.42). When Lavoisier revolutionized chemistry, in 1789, his *Preliminary Discourse* was an anthem for the importance of a precise denomination: “as ideas are preserved and communicated by means of words, it necessarily follows that we cannot improve the language of any science without at the same time improving the science itself; neither can we, on the other hand, improve a science, without improving the language (...). However certain the facts of any science may be, and, however just the ideas we may have formed of these facts, we can only communicate false impressions to others, while we want words by which these may be properly expressed” (Lavoisier, 1790/1965).

Another example of difficulty in understanding chemistry related to the language appeared at the problem-solving phase. Desulphurization equipment is the only efficient method to suppress the cause of pollution. This equipment performs the desulphurization of fossil fuels, that is, it removes the sulphur from these kinds of fuels. However, taking into account that the individuals who participated in this research were all Portuguese speakers, the relation between the word “enxofre” (sulphur) and the affix “sulfur”, which composes the word “dessulfurizador” (desulphurization equipment) is not clear. In this sense, the association of terms can point out the difficulty some research participants had in applying a more efficient method of air pollution control, even if the lack of attention on reading the topics about the equipments is added to this difficulty.

On the other hand, at the beginning of the problem solving, Claudio presented a hypothesis very similar to the desulphurization process of fossil fuels. After identifying the causal relation, he was asked how to solve the problem. His answer was:

Claudio: “I’m not sure. Perhaps I could find a way of treating sulphur; maybe until it is totally eliminated.”

When Cláudio was still navigating on the hypertext, he tried to install a desulphurization equipment, but the program did not allow it because he still had not concluded the problem identification step. However, he explained how the equipment worked, deducing its success:

Claudio: “It seems to be the most appropriate equipment because it removes the sulphur before the combustion.”

While using the program, Claudio understood that he had to fill in the first report before installing antipollution equipments. Afterwards, the decision of installing the desulphurization equipment was maintained, and he did not try the installation of any other equipment either to confirm his hypothesis or to find alternative solutions. In this sense, Claudio was quite sure about what he wanted to do; since the procedures he adopted were necessary to confirm the hypothesis he was following to solve the problem.

Multiple profiles of the environmental analysis

Eventually, some observations about the interdisciplinary integration provided by the environmental analysis are appropriate. In this research, none of the 8 participants showed an

integration of all the different systems related to the environmental issues. However, it could not be different, Fowler and Aguiar (1995) had already warned about the difficulty in verifying the integration of these systems even in professional practice itself. Nevertheless, participants represented most of the systems through the use of several notions related to the environmental issues.

Among the several conducts studied, we observed a typical example of the environmentalist thought; very similar to the environmental consciousness-raising campaigns that are disseminated without the required objectivity:

Carolina: *"I think that... [pause] What is causing the problem? I think that it is ourselves who cause the problem"*.

This behavior was also noticed in Carolina's propose to solve the problem, when she spontaneously reported education strategies:

Carolina: *"Let's suppose that there were people living in this town, real people..."*

I: *"Yes, but how the problem could be solved?"*

Carolina: *"We could solve it showing to the people what they are doing ...the wrong things."*

Further on, she revealed again her understanding beyond the program, demonstrating her apprehension with environmental issues:

Carolina: *"Let's suppose, O.K., that there are people in this place... [Carbopolis region] If it was happening to us, I would stick posters, go to the TV in order to help people to take conscience of what they were doing [polluting the air, building things at the wrong place, etc., as stated in her initial hypothesis]."*

Carolina's generalized environmentalism did not deny her the possibility of reformulating her hypothesis towards the objectivity. In this sense, it is important to highlight that this hypothesis reformulation was always oriented by a thought focused on the nature, ecology, ecosystems and on the emergency of environmental problems. Before the objectification, Carolina had already talked about urban pollution problems caused by vehicles, the location of the coal mine and the plant, ozone layer hole, etc.

Piter considered that it could be interesting to make the economical issues more present in the software, suggesting the inclusion of a maximum credit to perform the samples, the analyses and the installation or removal of the antipollution equipments. It may indicate that he could have proceeded in a different way, more precisely and efficiently, if the program had a feature that fitted such an idea.

Regarding juridical notions, sometimes the lack of attention, little interest or fast conclusions led to solutions that were not associated with the topic in which part of a legislation about the subject is related. Thus, it is interesting to verify that Piaget (1972) had mentioned the possible difficulties to the emergence of the juridical thinking.

Finally, besides the partial descriptions, there was a solution that was undoubtedly considered the standard solution associated to the chemical-physical system:

Claudio (describing in detail the causes of the problems, based on his report): *"The coal mine has a high rate of sulphur (6%). This sulphur is used by the Thermoelectric Station to produce electric energy. In the combustion of coal, sulphur is mixed to the air and forms the sulphur dioxide. Rainwater reacts with dioxide and then the acid rain is originated. This acid rain is the cause of the death of animals and of the destruction of plantations;"*

and Claudio (based on his report, describing the amounts involved in the problem): “*Sulphur concentration in the air atmosphere was quite higher than the level permitted by law. The maximum level permitted was 0.11 mg/m³, but levels higher than 1.8 mg/m³ were found in the analysis.*”

CONCLUSION

The general objective of our research was to demonstrate the cognitive conducts revealed by the research participants during the environmental analysis of a computer-simulated air pollution problem. In this sense, the specific objectives were to understand:

- 1) the individuals’ representations of the proposed problem;
- 2) the chaining of their procedures aiming at solving the problem;
- 3) the conceptual development during the problem solving.

The theoretical basis selected for this study was microgenesis (Inhelder & Cell erier, 1992). Microgenesis has a research model which allows inferring the accomplishment of procedures and understandings manifested by the individuals during a problem solving.

In short, two kinds of individuals’ cognitive system controls were identified during the problem solving. The existence of these two controls was also revealed in different research contexts (Bindra, Clarke, & Shultz, 1980; Mosca, Silveira, & Burigo, 1993; Beasley & Waugh, 1997; Park & Pak, 1997; Jacques & Fagundes, 1999). In one of these cognitive system controls, the individuals formulate a hypothesis for the problem and, from this hypothesis they apply their strategies and procedures when facing the problem. In the other kind of control, the individuals interpret the characteristics of the environment on which the proposed problem is presented and build new procedures systems.

With regard to the knowledge domain contemplated by this research, we believe that it would be possible to get to some conclusions. Thus, we could say that there are individuals with different profiles in relation to environmental issues. There are individuals who are oriented by economical notions, others by law principles, and individuals who are guided by models of the natural science’s descriptions and explanations. Not to mention those who support campaigns and understand that the publicizing of information would lead to a change of attitudes. Thus, the profiles are many and quite different. We understand then that strategies that aim at the understanding of the emergency of environmental issues should privilege a major cooperation between individuals who have these different profiles.

Finally, even though it was not mentioned throughout this paper, this research is related to the evaluation of a pedagogical project subjacent to computerized didactical material, such as the Carbopolis software, developed by two of the authors of this paper (Eichler et al., 2003). The subject of this didactical material is the means of production of electric energy and their environmental and social impact. In this research, we could verify that the Carbopolis software enabled individuals with various profiles to reconstruct the causal nexus of the simulated problem and solve it through different ways. In this sense, we understand that, on one hand, teaching and learning strategies focused on environmental issues can be associated to the use of various technologies, among them the computer simulations. On the other hand, we attempt to incorporate to the activities of our educational informatics project other tools (e-mail lists, forums or chat-rooms) that could favor the discussion among individuals who have the different profiles observed in this research.

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REFERENCES

- Agelidou, E., Balafoutas, G., & Flogaitis, E. (2000). Schematisation of concepts. A teaching strategy for environmental education implementation in a water module third grade students in junior high school (gymnasium – 15 years old). *Environmental Education Research*, 6, 223-243.
- Barab, S.A., Bawdish, B.R., & Lawless, K.A. (1997). Hypermedia navigation: profiles of hypermedia users. *Educational Technology Research and Development*, 45 (3) 23-41.
- Beasley, R.E. & Waugh, M.L. (1997). Predominant initial and review patterns of navigation in a fully constrained hypermedia hierarchy: an empirical study. *Journal of Educational Multimedia and Hypermedia*, 6 (2) 155-172.
- Bindra, D., Clarke, K.A., & Shultz, T.R. (1980). Understanding predictive relations of necessity and sufficiency in formally equivalent “causal” and “logical” problems. *Journal of Experimental Psychology: General*, 109, 422-443.
- Blanchet, A. (1992). Les unités procédurales, causales et téléonomiques dans l'étude des processus cognitifs. In B. Inhelder & G. Cellérier (eds.), *Le cheminement des découvertes de l'enfant*, pp. 93-114). Neuchâtel : Delachaux et Niestlé.
- Duveen, J. & Solomon, J. (1994). The great evolution trial: use of role-play in the classroom. *Journal of Research in Science Teaching*, 31, 575-582.
- Eichler, M.L. & Del Pino, J.C. (2000). Carbópolis: Um software para educação química. *Química Nova na Escola*, 11, 10-12.
- Eichler, M.L., Del Pino, J.C., Pesa Filho, F.L., & Vianna, V. (1998). *Carbópolis (Versão 1.1)* [Software]. Porto Alegre: Área de Educação Química. [<http://www.iq.ufrgs.br/aeq/carbop.htm>]
- Eichler, M. & Fagundes, L.C. (2001). A microgênese da explicação de um problema ambiental, os casos Paulo e Piter. *Psicologia: Reflexão e Crítica*, 14, 505-520.
- Eichler, M.L., Gonçalves, M.R., Silva, F.O.M., Junges, F., & Del Pino, J.C. (2003). Virtual learning environments designed in Brazil. *Educational Technology*, 43 (6) 58-60.
- Farynaiarz, J.V. & Lockwood, L.G. (1992). Effectiveness of microcomputer simulations in stimulating environmental problem solving by community college students. *Journal of Research in Science Teaching*, 29, 453-70.
- Fiedler, H., Martins, A.F., & Solari, J.A. (1990). Meio ambiente e complexos carboeléticos: O caso Candiota. *Ciência Hoje*, 68 (12) 38-45.
- Fiedler, H. & Solari, J.A. (1991). Concentração de metais em aerossóis atmosféricos. *Ambiente*, 5 (1) 26-32.
- Fowler, H.G. & Aguiar, A.M.D. (1995). A integração da teoria ecológica na análise ambiental. Em S.M. Tauk-Tornisielo, N. Gobbi & H.G. Fowler (orgs.), *Análise ambiental: Uma visão multidisciplinar*, pp. 166-175. São Paulo: Editora da Universidade Estadual Paulista.
- Furió, C.J., Iturbe, J., & Reyes, J.V. (1995). Cuánto contaminará una central térmica que funcionan con fuel? Un ejemplo de resolución de problemas como investigación. *Alambique: Didáctica de las Ciencias Experimentales*, 5 (La resolución de problemas) 27-36.
- Giacoaia JR., O. (1996). Hans Jonas: O princípio da responsabilidade. *Cadernos de História e Filosofia da Ciência*, 6 (2) 63-84.
- Hampton, E. (1993). The great oil spill cleanup contest [CD-ROM]. *Science Scope*, 16, 16-19. Abstract from ERIC, item EJ473485.
- Hösle, V. (1992). *Filosofia della crisi ecologica*. Torino: Einaudi.
- Inhelder, B., Ackermann-Valladão, E., Blanchet, A., Karmiloff-Smith, A., Kilcher-Hagedorn, H., Montangero, J., & Robert, M. (1976). Des structures cognitives aux procédures de découverte: Esquisse de recherches en cours. *Archives de Psychologie*, 44 (171), 57-72.
- Inhelder, B. & Caprona, D. (1992). Vers le constructivisme psychologique : Structures ? Procédures ? Les deux indissociables. In B. Inhelder & G. Cellérier (eds.), *Le cheminement des découvertes de l'enfant*, pp. 7-37. Neuchâtel : Delachaux et Niestlé.

- Inhelder, B. & Cellérier, G. (1992). *Le cheminement des découvertes de l'enfant*. Neuchâtel : Delachaux et Niestlé.
- Institute for Environmental Education, EUA (1994). *Closing the loop: Integrated waste management activities for school & home* (K-12 edition - A school-based waste minimization and education program on CD-ROM). Changin Falls, Ohio, EUA: Institute for Environmental Education. Abstract from ERIC, item ED404114.
- Jacques, T.G. & Fagundes, L.C. (1999). Procedimentos: O desenrolar das ações/operações na construção de apresentações hipermédia. *Informática na Educação: Teoria & Prática*, 2 (2) 99-108.
- Jonas, H. (1985). *The imperative of responsibility*. Chicago: University of Chicago Press.
- Kankaanrinta, I. (1991). Studying a finish Forest ecosystem with a simulation program. *Computers Education*, 16 (1) 105-108.
- Laszlo, P. (1994). *La Parole des choses ou le langage de la chimie*. Paris: Hermann.
- Lavoisier, A.L. (1790/1965). *Elements of chemistry: In a new systematic order, containing all the modern discoveries* (Trans. R. Kerr). New York: Dover Publications.
- Lawson, A.E. (1983). The effects of causality, response alternatives and context continuity on hypothesis testing reasoning. *Journal of Experimental Education*, 46 (1) 41-46.
- Moro, M.L.F. (2000). A epistemologia genética e a interação social de crianças. *Psicologia: Reflexão e Crítica*, 13 (2) 295-310.
- Mosca, P.R.F.; Silveira, J.F.P & Burigo, E. (1993). Processos cognitivos na resolução de problemas no campo da matemática: o caso da interação com programas-semente. *Psicologia: Reflexão e Crítica*, 6 (1/2) 57-83.
- Müller, M.L. (1996). Vittorio Hösle – Uma filosofia da crise ecológica. *Cadernos de História e Filosofia da Ciência*, 6 (2) 9-62.
- Park, J. & Pak, S. (1997). Student's responses to experimental evidence based on perceptions of causality and availability of evidence. *Journal of Research in Science Teaching*, 34, 57-67.
- Piaget, J. (1972). Intellectual evolution from adolescent to adulthood. *Human Development*, 15, 1-12.
- Saada-Robert, M. (1992). Didier et les poupées russes: Analyse de cas et conceptualisation. In B. Inhelder & G. Cellérier (eds.), *Le cheminement des découvertes de l'enfant*, pp. 139-169. Neuchâtel : Delachaux et Niestlé.
- Sheehy, N.P., Wylie, J.W., McGuinness, C., & Orchard, G. (2000). How children solve environmental problems: using computer simulations to investigate systems thinking. *Environmental Education Research*, 6 (2) 109-126.
- Siegler, R.S. & Crowley, K. (1991). The microgenetic method: a direct means for studying cognitive development. *American Psychologist*, 46, 606-620.
- Stake, R.E. (1994). Case study. In Em N. Denzin & Y. Lincoln (org.), *Handbook of Qualitative Research*, pp. 235-247. London: Sage.
- Taack, D.L. (1994). Minto-Brown Island Park: A case study of farming the urban-agricultural interface [CD-ROM]. *Journal of Natural Resources and Life Sciences Education*, 23, 98-103. Abstract from ERIC, item EJ 510818.
- Taylor, J.L. (1985). *Guide de la simulation et des jeux pour l'éducation relative a l'environnement* (Education environnementale, V.2). Paris: UNESCO.
- Whisnant, D.M. (1984). Scientific exploration with microcomputer: Simulations for nonscientists. *Journal of Chemical Education*, 61, 627-629.
- Whisnant, D.M. (1992). A role-playing exercise using a computer simulation. *Journal of Chemical Education*, 69, 42-43.
- Whisnant, D.M. & McCormick, J.A. (1992). Lake study for Windows. *Journal of Chemical Education*, 69, 129-130.
- White, P.A. (1997). Naïve ecology: Causal judgments about a simple ecosystem. *British Journal of Psychology*, 88, 219-233.
- Winter, D.D.N (1995). *Ecological psychology: Healing the split between planet and self*. Nova Iorque: Harper Collins.
- Wylie, J.W., Sheehy, N.P., McGuinness, C., & Orchard, G. (1998). Children's thinking about air pollution: a systems theory analysis. *Environmental Education Research*, 4 (2) 117-137.