Biology students' misconceptions of the carbon cycle: an analysis of their drawings

Ideas falsas de los estudiantes de la biología del ciclo de carbón: un análisis de sus dibujos

MUSA DIKMENLI

Selcuk University, Ahmet Kelesoglu Faculty of Education, Department of Biology Education, 42090, Konya, Turkey, mdikmenli@selcuk.edu.tr

Abstract

The purpose of this study was to identify biology students' misconceptions of carbon cycle using drawings and interviews. As a result of an analysis of the drawings and interviews, it was determined that more than half of the students have fully or partially conceptual knowledge, but 30% of students have misconceptions about this subject. Some of these misconceptions included "The carbon cycle is only composed of photosynthesis and respiration processes"; "Starting point of the carbon cycle is photosynthesis, and end point is cellular respiration"; "Only source of carbon is in the atmosphere". These results were compared with related literature and recommendations were made for teachers and researchers for future studies to overcome students' misconceptions.

Key words: *the carbon cycle, students' drawings, misconceptions.*

Resumen

Este trabajo se realizó con base en los dibujos y las entrevistas con los estudiantes con el fin de destacar los conceptos erróneos de los estudiantes de universidad en biología con respecto al ciclo del carbón en el ecosistema. A raíz del análisis de los dibujos y entrevistas, se constató que más de la mitad de los estudiantes posee información conceptual completa o parcial, pero que un 30% de los estudiantes tuvieron información errónea a este respecto. Algunos de estos conceptos erróneos son los siguientes: "El ciclo del carbón consta solamente de los procesos de fotosíntesis y respiración", "el inicio del ciclo del carbón es la fotosíntesis, su punto de llegada es la respiración celular", el único recurso del carbón es la atmósfera". Los resultados se compararon con la literatura y se desarrollaron los consejos para los docentes e investigadoresa como correguir estas concepciones falsas.

Palabras clave: *ciclo del carbón, dibujos de los estudiantes, concepciones falsas.*

INTRODUCTION

The term "misconceptions" has been coined to describe alternative conceptions, naive theories or views of science which do not overlap with concepts currently accepted by the community of scientists. Students' misconceptions are often deeply rooted, instruction-resistant obstacles to the acquisition of scientific concepts and remain even after instruction. Misconceptions are part of a larger knowledge system that involves many interrelated concepts that students use to make sense of their experiences. Students hold misconceptions developed before and during their early school years, and these misconceptions may be compounded by the teacher or the textbook (BAHAR, 2003; WANDERSEE, MINTZES & NOVAK, 1994).

Many misconceptions have been identified concerning ecology and the environment (EKBORG, 2005; CARLSSON, 2002). However, no detailed research was found relating to the carbon cycle, which is actually one of significant concepts of ecology. If teachers and curriculum designers knew students' misconceptions, it might be helpful to prepare effective teaching schemes. In this situation, teachers can play an important role in teaching scientific concepts. It is significant in terms of a constructivist perspective that students should have meaningful knowledge about ecological and environmental concepts like carbon cycle. ADENIYI (1985) studied students' common misconceptions on food chains, energy flow and the carbon cycle. It is concluded that although some of the misconceptions might have existed before the instruction, a few of them appeared after the instruction, and their prior misconceptions tended to block the understanding of new concepts and generalizations. Smith and ANDERSON (1986) searched alternative concepts of students about matter cycles in ecosystems. They found that students' conceptions of matter cycling processes remained fragmented even after instruction; only 4% of students understood that matter is converted back and forth between organisms' bodies and chemicals (carbon dioxide, water and minerals) in the environment. LEACH, DRIVER, SCOTT and WOOD-ROBINSON (1996) identified the 'key ideas' relating to the nature of living organisms, and the relationship between organisms based upon the cycling of matter and energy flow. These key ideas were used to identify students' understanding of ecological phenomena. It was found that, while the young children characteristically thought of organisms only in the context of human activity, they could not determine any relationship between organisms in ecosystems.

SUMMERS, KRUGER, CHILDS and MANT (2000, 2001) researched the understandings of teachers and trainee teachers about biodiversity, the carbon cycle and global warming. They found that the knowledge of the participants about the carbon cycle was limited compared to other fields. LIN and HU (2003) arranged for 106 students from 7th class to draw concept maps about energy flow and matter cycle and then analysed them. Results of their analyses indicated that the majority of students failed in defining the relationship between different concepts about the cycle of matter and energy flow.

Living things have to exchange matter with their environment in order to survive. This movement of matter between the living and non-living environment is called as nutrient cycling. Being one of the most important concepts of ecology, nutrient cycles must be reviewed in order to understand ecology well. The complicated relationships of organisms with each other and with their environment can be interpreted with an ecological approach. Environmental problems have increased due to the progress in technology and industry today. Moreover, a number of environmental problems have resulted from the lack of awareness of people with regards to this issue. These problems increase the importance of understanding the nutrient cycling in the environment. The carbon cycle is one of the most significant concepts of ecology, since life on the earth depends on this.

There are a number of techniques used to determine conceptual understanding and misconceptions of students. Open ended questions, two-tier diagnostic tests and interviews may be given as examples of these techniques. In addition, science educators also use drawings methods to assess students' understanding and their misconceptions. Student drawings in the area of biology can provide useful insight into common misconceptions (Kose, 2008; PROKOP & FANCOVICOVA, 2006; TUNNICLIFFE & REISS, 1999).

METHODOLOGY

The purpose of this study was to identify biology students' misconceptions of carbon cycle in the ecosystem using drawings and interviews.

A total of 134 students, who were studying to become secondary biology teachers at the Faulty of Education in Selcuk University in Turkey, participated in this study. The average age of the students was 22.8 years (range 21-26). The majority of students were females (95 of 134). Participants previously had been studying about carbon cycle in general biology, plant physiology, and ecology, as a school subject during various semesters. Research was conducted in May 2008. Biology students' understanding of the carbon cycle was examined by two different methods not mutually exclusive: 1) students' drawings 2) individual interviews. The participating students were asked to draw the carbon cycle in an ecosystem on a blank piece of A4-sized paper. Students' responses to drawing activity were analyzed using a coding framework prepared by KOSE (2008) and, REISS and TUNNICLIFFE (2001). Drawings were dealt with as a whole and analyzed with the method of point scoring by taking into account units on the drawings. Five levels of conceptual understanding were identified for this investigation—no drawing, non-representational drawings, drawings with misconceptions, partial drawings, and comprehensive representation drawings. Details of the levels were as follows:

Level 1: No Drawing: Students replied, "I don't know," or no response was given to the statement.

Level 2: Non-Representational Drawings: These drawings included identifiable elements of the carbon cycle. Also the responses, which included diagrams or formulations instead of the drawings, were evaluated in this category (Figure 1).

Level 3: Drawings with Misconceptions: These types of drawings showed some degree of understanding of the carbon cycle concepts, but also demonstrated some misconceptions. This category is illustrated in Figure 2 a, b.

Level 4: Partial Drawings: The drawings in this category demonstrated partial understanding of the concepts. They included elements of the carbon cycle like producer, consumer, photosynthesis, cellular respiration, atmosphere, etc. (Figure 3).

Level 5: Comprehensive Representation Drawings: Drawings in this category were the most competent and realistic diagrams of the carbon cycle (Figure 4). Drawings showing sound understanding, contained seven or more elements of the validated response for that particular statement (Table 1).

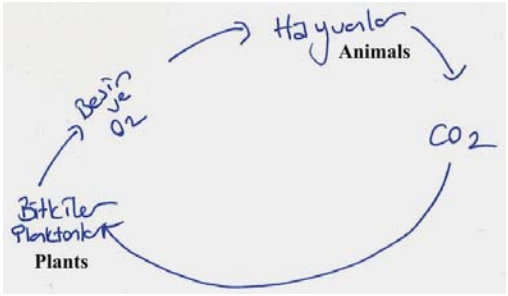

Figure 1. Example of level 2 (Non-Representational Drawing)

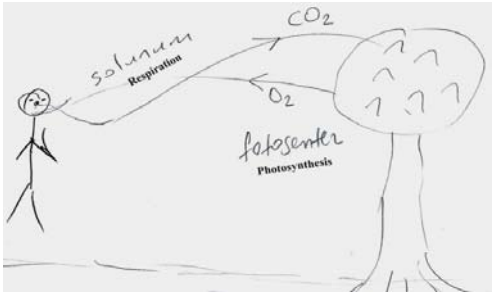

Figure 2a. Example of level 3 (Drawing with Misconception)

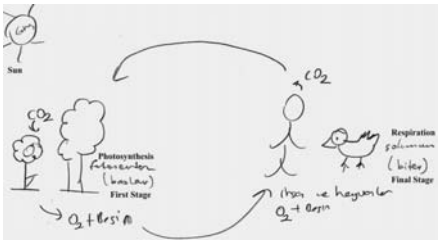

Figure 2b. Example of level 3 (Drawing with Misconception)

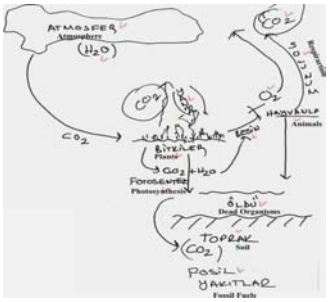

Figure 3. Examples of level 4 (Partial Drawing)

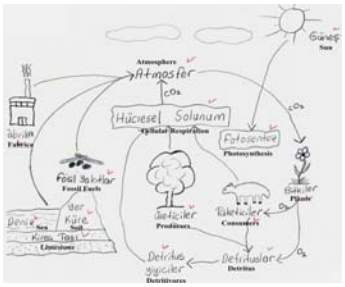

Figure 4. Examples of level 5 (Comprehensive Representation Drawing)

After the drawings were evaluated according to the above criteria, individual interviews were conducted with 15 randomly [how were they randomly selected]chosen students (9 female, 6 male) who demonstrated misconceptions. The purpose was to check the validity of the interpretation of the drawings. In the interview, these students were asked to respond to questions like 'What is the carbon cycle in your opinion', 'What happens in the carbon cycle if detritivores like nematodes and insect larvae suddenly stop their activities', 'What are the effects of human activities on the carbon cycle in your opinion', 'Is there a relationship between the carbon cycle and oxygen cycle', 'What are the actual stores of carbon in the biotic and abiotic environment'. Their responses are given below by comparing with the drawings.

RESULTS

In this study, the drawings were analyzed according to the criteria stated above to determine biology students' conceptual understandings and misconceptions related to carbon cycle (Figure 5). When Figure 5 is examined, it was found that 33% of the students concentrated on partial drawings (level 4). The number of students that had misconceptions was determined as 30% (level 3). In addition, it was also reported that 19% of students made comprehensive representation drawings (level 5) but 16% made non-representational drawings (level 2). Moreover, it was detected that 2% of students did not make any drawing. These results indicate that more than half of the students have fully or partially conceptual knowledge, but 30% of students have misconceptions about this subject.

The elements most frequently referred to by students relating to the carbon cycle are presented in Table 1, which shows that more than half of students concentrate on elements like producers, consumers, carbon dioxide, detritivores/decomposers, oxygen, photosynthesis and cellular respiration. On the other hand, it is reported that less than half of students displayed the elements like atmosphere, food, sun light, fossil fuels, detritus, water, soil, industrial waste and chemosynthesis in their drawings. These results suggest that the knowledge of students related to the carbon cycle is limited to the flow of carbon in living systems. Students think that the carbon cycle only contains photosynthesis and cellular respiration processes. More than half of students rarely consider the elements of the carbon cycle like atmosphere, human activities and fossil fuels. Moreover, it is also reported that students do not mention anything about the roles of oceans and volcanoes as significant sources of carbon.

Figure 5. Student's understandings of the carbon cycle as shown in their drawing

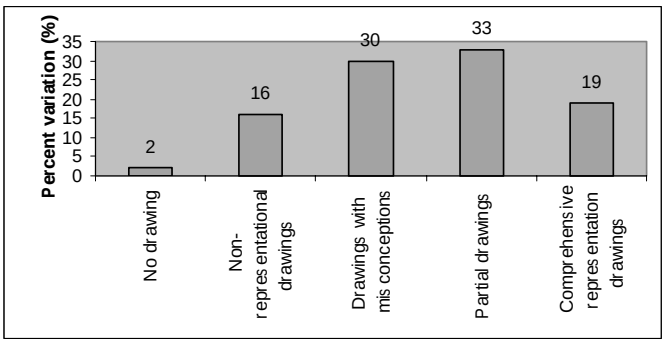

Table 1

The most frequent elements of the carbon cycle drawn by students

Elements for the carbon cycle	n	%
Producers	121	90
Consumers	113	84
Carbon dioxide	97	72
Detritivores / Decomposers	92	68
Oxygen	73	54
Cellular respiration	71	53
Photosynthesis	69	51
Atmosphere / Air	61	45
Food / Carbohydrate	42	31
Sun light	38	28
Fossil Fuels	36	27
Detritus	36	27
Water	24	18
Soil	23	17
Industrial wastes	6	4
Chemosynthesis	5	3

Nine misconceptions were determined in total as a result of the analyses on students' drawings. These misconceptions are given in **Table 2**.

Table 2

Misconceptions about the carbon cycle obtained in the drawings.

Misconceptions	n
1 The carbon cycle is only composed of photosynthesis and respiration processes	29
2 Carbon just goes and returns between producers and consumers in the carbon cycle	24
3 Starting point of the carbon cycle is photosynthesis and end point is cellular respiration	18
4 Plants photosynthesize, animals and humans respire during the course of the carbon cycle	15
5 Only source of carbon is the atmosphere	11
6 Plants convert carbon dioxide into oxygen, animals convert oxygen into carbon dioxide	9
7 Carbon released to the atmosphere combines with oxygen and so carbon dioxide is formed	3
8 Inorganic carbon is formed after cellular respiration	3
9 Plants produce protein and oxygen through photosynthesis	2

In addition, a number of misconceptions were determined as a result of interviews randomly selected among students having misconceptions in their drawings. Misconceptions obtained from interviews are given in Table 3.

Table 3

Misconceptions about the carbon cycle obtained in the interviews

Misconceptions
- Energy required for the carbon cycle is provided by nitrification and denitrification bacteria.
- Plants convert carbon dioxide into oxygen, animals convert oxygen into carbon dioxide.
- CO_2 is only transferred to the air as a result of decomposition of organic wastes.
- Matter cycle is transmutation of matters physically as solid, liquid and gas.
- The carbon cycle is just the process of synthesizing from inorganic carbon to organic carbon.
- The amount of carbon dioxide in the atmosphere will increase if detritivores disappear.
- The carbon cycle will completely stop in a short period if detritivores disappear.
- The amount of carbon on our planet is gradually increasing as a result of burning fossil fuels.
- Burning fossil fuels like coal releases CO_2 confined in them.
- The carbon cycle is only composed of photosynthesis and respiration processes.
- Starting point of the carbon cycle is photosynthesis and end point is cellular respiration.
- Starting point of the carbon cycle is cellular respiration and end point is photosynthesis.
- Only source of carbon is the atmosphere.

Some of the significant misconceptions obtained from the interviews were as follows. Seven of the interviewed students mentioned the carbon cycle is only composed of photosynthesis and respiration processes. None of these students mentioned about other significant parts of the cycle like detritus, detritivores and fossil fuels. This misconception obtained from the interviews was also found in the drawings (Figure 2a). Three of the interviewed students mentioned that burning fossil fuels like coal releases the CO_2 trapped in the coal. These students had the idea that CO_2 is trapped in fossil fuels. Five of the interviewed students mentioned that carbon is only circulated between producers and consumers in the carbon cycle. This misconception was also found in drawings of students (Figure 6). None of these students mentioned the significance of detritus and fossil fuels in the carbon cycle.

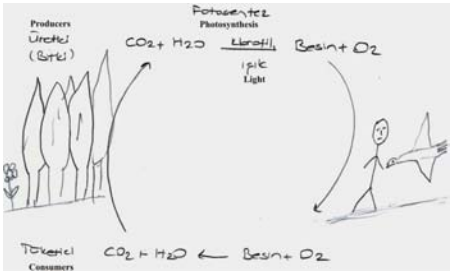

Figure 6. A Drawing of the misconception that carbon is only circulated between producers and consumers in the carbon cycle.

Two interviewed students mentioned that carbon is only circulated between living systems. These students did not mention about carbon resources in the non-living environment of the ecosystem. Two interviewed students mentioned that the starting point of the carbon cycle is photosynthesis and the end point is cellular respiration (Figure 2b). These students believe that carbon in the ecosystem circulates only between the atmosphere, plants and animals. Two interviewed students mentioned that the amount of CO_2 in the atmosphere will increase if the detritivores disappear. These students did not mention about the issue that the amount of CO_2 in the atmosphere will decrease if the detritivores disappear. One interviewed student mentioned that the energy required for the carbon cycle is provided by nitrification and denitrification bacteria. One interviewed student mentioned that plants convert carbon dioxide into oxygen and that animals convert oxygen into carbon dioxide during the course of the carbon cycle. In addition, one student mentioned that nutrient cycles, including the carbon cycle, is transmutation of nutrients physically as solid, liquid or gas.

It is seen that misconceptions identified in the interviews are consistent with the misconceptions detected on the drawings. This situation verifies the validity of misconceptions obtained from drawings. For example, seven of the interviewed students mentioned that the carbon cycle is only composed of photosynthesis and respiration processes. This misconception was also found in 29 of the drawings (Figure 2a). In addition to this, five students mentioned that carbon is only circulated between producers and consumers in the carbon cycle. None of these students mentioned about significant circles like detritus and fossil fuels included in flow of the carbon cycle. This misconception was also found in 24 of the drawings (Figure 6).

DISCUSSION

The use of student drawings and interviews with an appropriate sample size ensured that we could determine the alternative viewpoints biology students have related to the carbon cycle. The most remarkable evidence from the study is that the majority of the students have misconceptions or partial knowledge about the carbon cycle. This evidence is surprising since the subject of the carbon cycle exists in the primary and secondary school curriculum.

Analysis of the drawings suggests that the conceptual understanding of students is weak especially in terms of circulation of the carbon cycle, the flow of carbon between living and non-living systems and the significant sources of carbon. Some of misconceptions determined are similar to misconceptions mentioned in previous research in Turkey and other countries on some periods of school life (Kose, 2008; Hellden, 2004; Lin & Hu, 2003; Summers, Kruger & Childs, 2000; 2001; Lavoie, 1997; Brody, 1993). However, some misconceptions determined in this research have emerged for the first time (Figure 2b). These are as follows: "Starting point of the carbon cycle is photosynthesis and end point is cellular respiration" "Carbon just goes and returns between producers and consumers in the carbon cycle", "The amount of CO_2 in the atmosphere will increase if detritivores disappear", "Only source of carbon is the atmosphere" and "The amount of carbon on our planet is gradually increasing as a result of burning fossil fuels". The existence of these misconceptions, despite the fact students are educated with various education techniques at the university, show that such misconceptions are extremely resistant against change. Therefore, the teachers at the primary and secondary education levels, and the lecturers at the university assume very important roles regarding employment of alternative teaching strategies to eliminate or at least minimize such misconceptions. If we consider the fact that such students will graduate from the university as biology teachers, with such misconceptions, is considered very important regarding the problems that arise during their tutorage. Effective teaching methods must be used to eliminate or minimize these misconceptions that the university students possess. Otherwise, the new teachers will continue teaching these misconceptions and the cycle is not broken. Conceptual change strategies like concept maps, concept networks and conceptual change texts are the methods which will reduce or eliminate misconceptions of students (Novak & Canas, 2004; Tekkaya, 2003).

Analyses indicate that students perceive "the carbon cycle" as an unimportant area of knowledge. Students understand various processes related with the carbon cycle but they do not understand the systematic structure of the carbon cycle as a whole. For this reason, perceptions of students relating to the cyclical structure of carbon may be clarified by their way of characterising a cycle by comparing it with a life cycle rather than a nutrient cycle. Drawings and interviews also displayed the misconceptions of students regarding the effects of human activity upon the carbon cycle and the relative amounts of different carbon reservoirs on the earth. This evidence is similar to that found in the study by Gudovich (1997) relating to the understanding of the carbon cycle by pupils in classes 11 and 12. Analysis of students' drawings revealed the difficulties experienced by students in associating formal education with real world phenomenon. While most students disregard

the effect of humans on the carbon cycle, interviews suggested that most of the students are aware of carbon dioxide increase in the atmosphere caused by humans. These results suggest that students cannot correlate their school learning with daily life regarding the carbon cycle.

CONCLUSIONS

This study has shown the difficulties and misconceptions relating to the understanding of the dynamic structure of the carbon cycle in an ecosystem. It clearly revealed that the students did not understand well the role of the carbon cycle in the ecosystem. Drawings made by students in this study demonstrated the existence of a number of misconceptions. Moreover, it was also shown that the knowledge of students regarding the carbon cycle is limited to the flow of carbon in living systems. Students think that the carbon cycle is only composed of photosynthesis and cellular respiration. More than half of students rarely consider the elements of the carbon cycle like atmosphere, human activities and fossil fuels. In addition, it was again noted that the drawing method, along with interviews, is an effective method in identifying misconceptions and concepts that students have difficulty in understanding. In this regard, the use of the drawing method in determination of misconceptions or preliminary knowledge is recommendeded in future studies.

BIBLIOGRAPHY

ADENIYI, E. O., Misconceptions of selected ecological concepts held by some Nigerian students. *Journal of Biological Education,* **19** (4), 311-316, 1985.

BAHAR, M., Misconceptions in biology education and conceptual change strategies. *Educational Sciences: Theory & Practice*, **3** (1), 55-64, 2003.

BRODY, M., Development of the project WET curriculum framework. *Proceedings of the American Water Resources Association Summer Symposia*, Seattle, WA, 1993.

CARLSSON, B., Ecological understanding 2: Transformation-A key to ecological understanding. *International Journal of Science Education*, **24** (7), 701-715, 2002.

EKBORG, M., Student-teachers' learning outcomes during science subject matter courses. *International Journal of Science Education*, **27** (14), 1671-1694, 2005.

GUDOVITCH, Y., *The global carbon cycle as a model for teaching 'earth systems' in high school: Development, implementation, and evaluation.* Unpublished master's thesis, the Weizmann Institute of Science, Rehovot, 1997.

HELLDEN, G., A study of recurring core developmental features in students' conceptions of some key ecological processes. *Canadian Journal of Science, Mathematics and Technology Education*, **4** (1), 59-76, 2004.

KOSE, S., Diagnosing student misconceptions: Using drawings as a research method. *World Applied Sciences Journal*, **3** (2), 283-293, 2008.

LAVOIE, D. R., Using a modified concept mapping strategy to identify students' alternative scientific understandings of biology. *Paper presentation at National Association for Research in Science Teaching,* Annual meeting at Chicago, IL, March 21-24, 1997.

LEACH, J.; DRIVER, R.; SCOOT, P. & WOOD-ROBINSON, C., Children's ideas about ecology 2: Ideas found in children aged 5-16 about the cycling of matter. *International Journal of Science Education,* **18** (1), 19-34, 1996.

LIN, C. Y. & HU, R., Students' understanding of energy flow and matter cycling in the context of the food chain, photosynthesis and respiration. *International Journal of Science Education*, **25** (12), 1529-1544, 2003.

NOVAK, J. D. & CANAS, A., Building on new constructivist ideas and Cmap tools to create a new model for education. *Proceedings of the First Int. Conference on Concept Mapping*, Pamplona, Spain, 2004.

PROKOP, P. & FANCOVICOVA, J., Students' ideas about human body: Do they really draw what they know? *Journal of Baltic Science Education*, **2** (10), 86-95, 2006.

REISS, M. J. & TUNNICLIFFE, S. D., Students' understandings about human organs and organ systems. *Research in Science Education*, **31**, 383-399, 2001.

SMITH, E. L. & ANDERSON, C. W., Alternative student conceptions of matter cycling in ecosystems. *Paper presented at the annual meeting of the National Association for Research in Science Teaching*, San Francisco, California, 1986.

SUMMERS, M.; Kruger, C.; CHILDS, A. & MANT, J., Primary school teachers' understanding of environmental issues: an interview study. *Environmental Education Research,* **6** (4), 293-312, 2000.

SUMMERS, M.; KRUGER, C.; CHILDS, A. & MANT, J., Understanding the science of environmental issues: development of a subject knowledge guide for primary teacher education. *International Journal of Science Education,* **23** (1), 33-53, 2001.

TEKKAYA, C., Remediating high schools' misconceptions concerning diffusion and osmosis through concept mapping and conceptual change text. *Research in Science and Technological Education*, **21** (1), 5-16, 2003.

TUNNICLIFFE, S. D. & REISS, M. J., Students' understandings about animal skeletons. *International Journal of Science Education*, **21** (11), 1187-1200, 1999.

WANDERSEE, J. H.; MINTZES, J. J. & NOVAK, J. D., Research on alternative conceptions in science. In D.L. Gabel (ed.), *Handbook of research on science teaching and learning.* (pp. 177-210). New York: Macmillan, 1994.

Received: 05-02-2009 / Approved 08-05-2010