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RESEARCH REPORT (EMPIRICAL STUDY)
Concepts

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STUDENTS' DIFFICULTIES IN UNDERSTANDING OF THE CONSERVATION OF MATTER IN OPEN AND CLOSED-SYSTEM CHEMICAL REACTIONS

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ABSTRACT: The law of conservation of matter is a cornerstone in the development and advancement of modern chemistry. With this idea in mind, a test of four items was designed and used to determine students' understanding about the conservation of matter in open and closed-system chemical reactions. The test was administered to 150 *lycee-2* (grade 10; age 15-16) students after they studied *the unit on chemical reactions.* The analysis of the collected data revealed that students had some misconceptions. One of the most common misconception encountered was that "*the total mass increases in a precipitation reaction because the precipitate produced is solid and it is heavier than a liquid*." Another misconception in parallel to the previous one was that "*when a chemical combustion happens in a closed system, the total mass decreases*." [*Chem. Educ. Res. Pract.*: 2003, *4*, 279-290]

KEY WORDS: *secondary education; misconceptions; conservation of matter; chemical reactions; open-system chemical reactions; closed-system chemical reactions*

INTRODUCTION

The science education literature contains several studies of students' understanding of scientific phenomena. These studies have revealed that students bring to instruction views and explanations of natural phenomena that differ from the views held by scientists (Osborne, 1982). Students' preconceptions are not only quite different from those generally accepted in science, but also they are quite resistant to ordinary classroom teaching (Stavy, 1991).

Such views of the world held by children are not simply isolated ideas but form conceptual structures that provide a coherent understanding of the world from the child's point of view (Gilbert *et al.,* 1982; Hackling & Garnett, 1985). In recent years, there has been an increasing interest to determine students' alternative views about science concepts and scientific events. These alternative views have been called in the literature common sense understanding (Hills, 1983), alternative frameworks (Driver, 1981), alternative conceptions (Driver & Easley, 1978; Gilbert & Swift, 1985), preconceptions (Novak, 1977; Hashweh, 1988), common alternative science conceptions (Gonzalez, 1997), prescientific conceptions (Good, 1991) or misconceptions (Helm, 1980; Hewson & Hewson, 1984, Lawson & Thompson, 1988; Treagust, 1988; Nakhleh, 1992). In this study, the term *misconception* refers to students' ideas which are different from those generally accepted by scientists.

Within the domain of chemistry, surveys have revealed that the topics of chemical equilibrium, the mole, oxidation-reduction, reaction stoichiometry, chemical bonding and chemical reactions give learners most difficulty (Finley *et al.*, 1982; Hackling & Garnett, 1985). Chemistry is a science whose primary purpose is the description and explanation of chemical changes (Hesse & Anderson, 1992). Since the concept of chemical reaction is considered to be an important objective of chemistry teaching, teachers should be made aware of students' difficulties in this area. The scientific understanding and applying of the conservation of mass in chemical reactions is problematical for many students. This concept is a central theme in the program of Junior High School (14-15 years old pupils), and also a prerequisite for the subsequent understanding of chemistry. From a scientific point of view, the understanding of the mass conservation principle, as well as the knowledge of the general theory of chemical reactions, is indispensable for the whole understanding of chemistry in subsequent studies (Paixão & Cachapuz, 2000). The law of conservation of matter is one of the very basic and fundamental laws of science, and is one of a set of known conservation laws. Scientists regard this law as empirical law, which states that atoms are neither created nor destroyed during a chemical reaction, the atoms of reactant are just rearranged to form the products. In other words, if we determine or calculate the mass of all the reactants and the mass of all the products, we find that they are equal; in other words, the total mass of the products in a chemical reaction must be equal to the total mass of the reactants. Such a result is expected according to the law of conservation of matter. The law determines the conditions in which each quantity is conserved. Ideas concerning the conservation of matter have been raised during the history of science and the problem of conservation of matter has occupied scientists at different times (Stavy, 1990).

There exists a lot of research that points out the existence of students' misconceptions concerning the concept of conservation of matter (Yarroch, 1985; Anderson, 1986; Ben-Zvi *et al*., 1987; Hesse & Anderson, 1992). Piaget and Inhelder (1974) examined children's ideas about it, using the concept of dissolving, and found that children's reasoning is governed by their perceptual experience: the children observed that sugar dissolved in water just disappeared, so that they predicted no change in the weight of water after dissolving the sugar in it. They attributed students' failure to understand the conservation of matter to their lack of logical operations. However, Stavy (1990) found conflicting results. She studied students' understanding of the concept using the processes of melting, dissolving, and evaporation, and discovered that while children pass some conservation tasks, they fail the others. She showed that logical operations are not enough to explain students' misconceptions about this concept, because the existence of an alternative system of knowledge affects students' ability to understand conservation.

Many other researchers in different countries showed that students have difficulties in understanding this concept. For example, Driver *et al.* (1984) and Andersson (1984) report the responses of 15-year-old students to a question about a piece of phosphorus placed in some water in a sealed flask which is heated by the sun. Students were told that the phosphorus catches fire producing a white smoke, which dissolves in water, and they were asked to state whether the final mass would be the same, greater, or less than the starting mass. Both research studies reported that about one-third of the sample gave conservation-type answers, suggesting that the mass would not change because "the flask is sealed". A further 16% thought the mass would decrease; only 6% thought the mass would increase. The same question was used in a study by Barker and Millar (1999) to probe students' ideas about conservation in closed-system chemical reactions. It was found that that some of the students who participated in the study had misconceptions, suggesting that the mass would decrease or the mass would increase.

Haidar (1997) studied prospective chemistry teachers' ideas about conservation of matter and related concepts. He found that only a very small proportion of subjects were able to show a sound understanding of the conservation of mass. While some subjects (about

17%) showed partial understanding with specific misconceptions, about 80% of the subjects had no understanding of this concept.

Ramsden (1997) and Barker and Millar (1999) studied students' thinking about conservation of mass in open-system chemical reactions by using the same question. The participating students were asked to predict whether the mass of two solutions mixed together to form a precipitate would change. Both studies found that the students had misconceptions about mass conservation in chemical reactions. While some of the students thought that mass would decrease, some others thought that mass would increase. Results indicated that the students used a naive model of matter, dependent on the sensory perception of expecting solids to be heavier than liquids.

The above literature has indicated controversial results in different countries, at different educational levels, about students' understanding of conservation of matter. To make the results found in the literature more convincing, some other studies in different contexts and at different levels should be done to reach further conclusions, so that new teaching materials and/or media could be developed. With this idea in mind, this study aimed to provide some more data to determine students' misconceptions about the conservation of matter in open and closed-systems chemical reactions at secondary level in Turkey.

METHODOLOGY

In Turkey, schooling consists of three main components: compulsory basic education (primary schools, age 6-14; 8 years), secondary education (*lycees* or senior high schools, age 14-17, 3 years), and higher education (colleges and universities). The elementary teaching of chemistry begins with a brief introduction of physical and chemical changes at the age of 10-11. Then introductory concepts such as atomic structure and chemical reactions are taught in general at the age of 13-14. Formal chemistry lessons start with secondary education at the age of 14-15. The chemical reactions unit is taught in lycee 2 (grade 10, age 15-16) in detail. The time devoted to this unit is 18 hours. However, the students have very limited chances to do laboratory activities during the teaching of the unit. The unit covers a number of concepts and reaction categories such as conservation of matter, limiting reagents, analysis, synthesis, combustion, and substitution reactions.

A test consisting of four items, two for open and two for close-systems chemical reactions, was designed. All items included a multiple-choice answer, plus an explanation of the answer. Three of the items were adapted from literature, while the fourth was designed by the authors. Content validity of the test was established by asking twelve experts (one chemistry education professor, one chemist with PhD degree, three science educators and seven chemistry teachers) to evaluate the degree to which the questions were representative of the content covered. In addition, thirty-two lycee-2 students were asked to confirm the clarity and readability of the test.

The test was administered to 150 lycee-2 students after they studied the unit on chemical reactions. Students' responses were analyzed in detail and their misconceptions about the conservation task were identified. After that, students' responses were classified into different categories in regard to their similarities and differences.

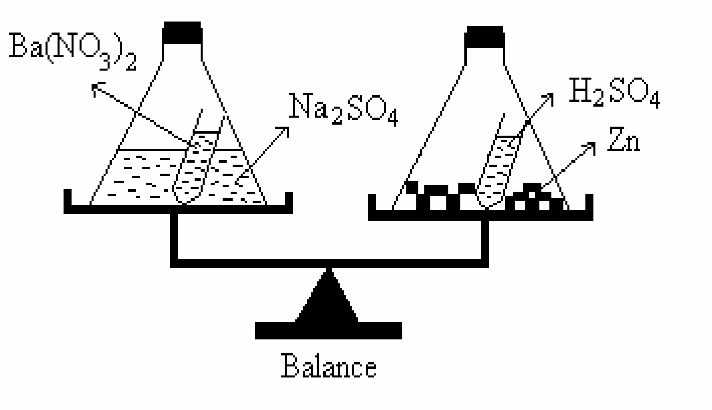
RESULTS

Item 1

In the following diagram reactants were put inside the flasks that were tightly sealed. Additionally the total weights of the two flasks on the balance are equal. When the two reactants in each flask are mixed by tilting the flasks, the following reactions take place:

$$Na_2SO_4 + Ba(NO_3)_2 \longrightarrow 2NaNO_3 + BaSO_4 \text{ (white precipitation)}$$
$$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2 \text{ (gas)}$$

What change occurs in the balance (1) at the beginning, and (2) at the end of the reactions?: (a) *balance does **not** change*; (b) *balance changes*; (c) *no response*. Explain your answer.



Item 1 involves the law of conservation of mass in a closed-system chemical reaction and was taken from the literature (Lin, 1998). Since the container is tightly sealed, no substance can escape. Although the reaction at the right side of the balance will produce a gas and the reaction at the left side of the balance will produce a precipitate, the two sides will remain balanced from the beginning to the end of the reactions.

Students' responses to item 1 are given in Table 1. 56% of the students stated that the balance would not change. These students gave conservation-type explanations. For example, while some of these students stated, "*because both flasks are sealed, nothing can escape, so the balance does not change",* the others stated that *"according to the law of conservation of mass, the total mass of the reactants is equal to the total mass of the products, so the balance does not change*".

TABLE 1. *Students' responses to Item 1.*

Responses	N	%
Balance is unchanged	84	56
Balance is changed	57	38
No response	9	6

38% of the students predicted change of the balance, suggesting a variety of explanations. For example, 18% of the students stated:

> "*at the beginning, the balance does not change because the masses are equal, but at the end of the reaction, H_2 gas is released at the right side of the balance. Because H_2 gas is lighter than air, the weight of the right side of the balance decreases and the balance changes*".

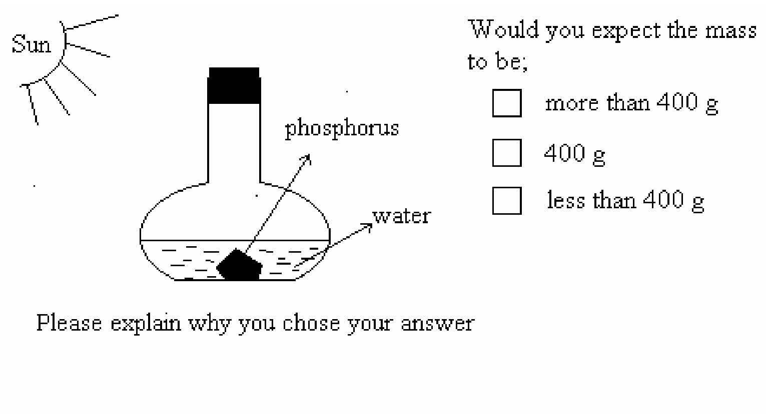
12% of the students stated that "*the reaction at the left side produces a precipitate, while the reaction at the right side produces a gas (H_2). Because the precipitate is heavier than the gas, the balance changes*". 8% of the students stated that:

> "*at the beginning of the reaction, there are 2 moles of substances at both sides [at the left side: 1 mol $Ba(NO_3)_2$ and 1 mol Na_2SO_4; at the right side: 1 mol H_2SO_4 and 1 mol Zn], so the two sides balance. However, at the end of the reaction, the reaction at the right side produces 2 moles of substances (1 mol $ZnSO_4$ and 1 mol H_2), while the reaction at the left side produces 3 moles of substances (2 moles $NaNO_3$ and 1 mol $BaSO_4$). At the end of the reaction, therefore, the left side is heavier than the right side*".

6% of the students did not respond to this question.

Item 2

> A piece of phosphorus and some water were placed in a flask. The flask was sealed with a rubber stopper. The mass of the flask and contents was 400 g. The sun's rays were focused on the phosphorus, which caught fire. White smoke was produced which slowly dissolved in the water. The flask was cooled and its mass measured again.



Item 2 also involves the law of conservation of mass in a closed-system chemical reaction and was taken from the literature (Barker, 1994; Driver *et al*., 1982; Murphy & Gott, 1984). In this case, two reactions occur. The first happens after the water has evaporated,

$$4P(s) + 5O_2(g) \longrightarrow 2P_2O_5(s)$$

The white smoke is P_2O_5. The second stage occurs on cooling:

$$3H_2O(l) + P_2O_5(s) \longrightarrow 2H_3PO_4(aq)$$

After the water condenses, the white smoke is dissolved in it, forming phosphoric acid. In this reaction, the mass will remain unchanged, despite the fact that a chemical reaction between oxygen and phosphorus takes place. Also, the flask is sealed, so nothing can escape.

Students' responses to item 2 are given in Table 2. 52% of the students selected the correct option (option b) and gave a good explanation, suggesting that "*nothing has left the flask and nothing has entered because the flask is sealed. White smoke has dissolved in water. Therefore, the weight will be the same*". Another student explained that, "*phosphorus*

TABLE 2. *Students' responses to Item 2.*

Responses	N	%
Wrong option (option a) and explanation	*15*	*10*
Wrong option (option a) and no explanation	*9*	*6*
Total	***24***	***16***
True option (option b) and explanation	*78*	*52*
True option (option b) and no explanation	*12*	*8*
Total	***90***	***60***
Wrong option (option c) and explanation	*24*	*16*
Wrong option (option c) and no explanation	*8*	*5*
Total	***32***	***21***
No response	*4*	*3*

is still present but it dissolves in water". An additional 8% of the students selected the correct option, but they did not give a reason.

10% of the students selected option a. They thought the mass would increase, suggesting that:

- *when the smoke dissolves in water, weight increases;*
- *gas produced is heavier than air, so weight increases;*
- *size of phosphorus increases on burning;*
- *gas produced dissolves in water, so flask is heavier;*
- *when the combustion occurs, some gases are produced, therefore weight increases;*
- *after the combustion, new materials occur, so flask is heavier than 400 g;*
- *phosphorus reacts with oxygen in the flask and a heavier substance is produced, so weight increases.*

Some of the students (6%) also selected option a, but they did not justify their choice.

16 % of the students selected option c. They thought the mass would decrease, suggesting that:

- *phosphorus dissolves in water, a solid is heavier than a gas, so flask becomes lighter;*
- *phosphorus dissolves in water, so only water is left;*
- *gas produced is less dense/heavy than solid (phosphorus);*
- *the energy from the sun evaporates water, only phosphorus is left, so weight decreases;*
- *after phosphorus dissolves in water, it is used up, so weight decreases;*
- *when a chemical combustion happens in a closed system, total mass decreases;*
- *before the experiment, the weight of the flask = phosphorus + water + flask;*
- *after the experiment, the weight of the flask = water + flask, so weight decreases.*

An additional 5% of students selected option c without justification.

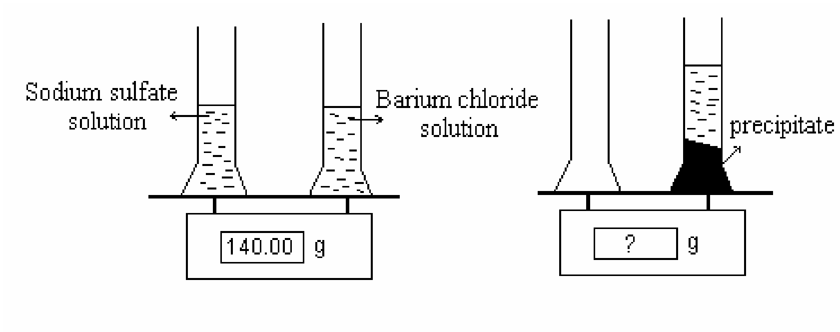
It is seen from Table 2 that, in total, 60% of the students gave conservation-type answers, suggesting that mass would not change because the flask was sealed. On the other hand, 37% of the students did not conserve mass, suggesting that mass would increase or decrease. The most common misconceptions were that "*a gas is lighter than a solid*", and "*mass decreases on dissolving*".

Item 3

Aqueous solutions of two salts, sodium sulfate, $Na_2SO_4(aq)$, and barium chloride, $BaCl_2(aq)$, are placed in separate measuring cylinders on a top-pan balance. The total mass is recorded as 140 g. The sodium sulfate solution is poured into the barium chloride solution. Both measuring cylinders stay on the balance. A precipitation reaction takes place. What will the mass reading be after the reaction?

☐ Less than 140g ☐ 140 g exactly ☐ More than 140 g

Explain why you think this happens.



Item 3 concerns conservation of mass in an open-system chemical reaction and was taken from the literature (Barker, 1994; Ramsden, 1997). The chemical idea being tested is "*mass is conserved when a precipitation reaction takes place*". The chemical reaction is:

$$BaCl_2\,(aq) + Na_2SO_4\,(aq) \longrightarrow BaSO_4\,(s) + 2NaCl\,(aq)$$

In this, the mass remains unchanged, because no substance is removed as a gas. Students' responses to Item 3 are given in Table 3. 43% of the students selected the correct option (option b) and gave good explanations, suggesting that:

- *because a gas is not released in the reaction, the mass of reactants is equal to the mass of products;*
- *exactly the same reactants are present in the products, only an exchange of ions takes place, so mass is the same;*
- *mass is the same because the number and kind of atoms do not change;*
- *mass is also conserved in an open system chemical reaction in which a gas is not released.*

TABLE 3. *Students' responses to Item 3.*

Responses	N	%
Wrong option (option a) and explanation	*18*	*12*
Wrong option (option a) and no explanation	*12*	*8*
Total	***30***	***20***
True option (option b) and explanation	*64*	*43*
True option (option b) and no explanation	*16*	*11*
Total	***80***	***54***
Wrong option (option c) and explanation	*24*	*16*
Wrong option (option c) and no explanation	*10*	*6*
Total	***34***	***22***
No response	*6*	*4*

Some students (11%) selected the correct option (option b), but they did not offer an explanation.

12% of the students selected option a. They thought mass would decrease, suggesting that:

- *because a gas was produced when the precipitate was formed;*
- *at the start there were two solutions, but at the end one new substance was produced; two solutions were mixed together, so weight would decrease.*

An additional 8% of students selected option a, without justification.

16% of the students selected option c. They thought the mass would increase suggesting that:

- *mass increases because solids weigh more than liquids;*
- *when the solution is poured into the other solution, its weight is added to that of the other solution;*
- *because a new substance (precipitate) is produced, weight increases.*

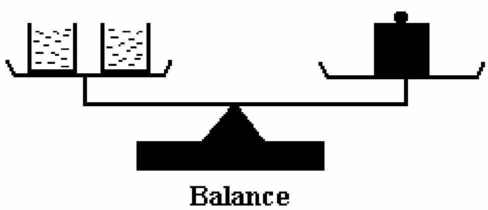
6% of the students selected the option c, without justification. Finally, 4% of the students did not respond to this question.

It is seen from Table 3 that, while 43% of the students responded with a formal statement of conservation, suggesting that "*mass is conserved in a chemical reaction",* 42% of the students did not conserve mass, suggesting that mass would increase or decrease. One of the most common misconceptions students have is that *"because a gas is released in the reaction, mass decreases*". Another common misconception is that "*a precipitate produced is a solid and it is heavier than a liquid"*. The formation of a solid in a precipitation reaction is a tangible event, but this idea must be considered a misunderstanding of the chemical idea. Finally, some students did not predict correctly the products of the reaction.

Item 4

> A student wants to carry out an experiment related to the law of conservation of matter. The experiment consists of two different solutions, weighed up on a balance system as shown in the figure. The student mixes the solutions and weighs the mixture again. According to the conservation law, after the mixing the system should be on balance again. Which one of the following solutions **should not** the student mix to demonstrate the law of conservation of matter? Explain your answer.

a. $HCl + NaOH$
b. $CaCO_3 + HCl$
c. $NaOH + FeCl_2$
d. $Ca(OH)_2 + H_2SO_4$
e. $AgNO_3 + NaCl$



Item 4 deals with conservation of mass in an open-system chemical reaction, and it was devised by the authors. Here, five different reactions in open systems occur. One of these five reactions (option b) will produce a gas:

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + CO_2 + H_2O$$

Because the system is open, the produced gas is released into the atmosphere. Therefore this reaction does not demonstrate the law of conservation of mass. The correct option is *b.*

Students' responses to item 4 are given in Table 4. 52% of the students selected the correct option, explaining that "*when $CaCO_3$ and HCl are mixed, a gas (CO_2) is produced. Because the system is open, the produced gas is released into the atmosphere*".

Table 4. *Students' responses to Item 4.*

Responses	N	%
Option *b*	78	52
Option *a* and *d*	60	40
No response	12	8

40% of the students selected option a and option d. These students stated that:

- *for option a,* $HCl + NaOH \longrightarrow NaCl + H_2O$
- *for option d,* $Ca(OH)_2 + H_2SO_4 \longrightarrow CaSO_4 + 2H_2O$

Both reactions produce water. Because the system is open, the water produced evaporates and mixes into the air. Therefore, the law of the conservation of mass is not demonstrated in this case. 8% of the students did not respond.

DISCUSSION AND CONCLUSIONS

The law of conservation of matter is a cornerstone in the development and advancement of modern chemistry. Therefore, it must be regarded as a basic knowledge item to be used to develop chemical ideas among students. The aim of this study was to probe students' understanding about the conservation of mass in chemical reactions occurring in open and closed systems. The findings showed that while about half of the tenth-grade students understand the conservation of matter in chemical reactions, the other half hold a number of misconceptions. Some students did not realize that the mass of a solution equals the mass of solute and solvent. The most common misconceptions students held about the conservation of mass in open and closed-system chemical reactions were:

"*a solid is heavier than a gas";*
"when phosphorus dissolves in water its weight is destroyed";
"a precipitate produced is heavier than a liquid";
"when a chemical combustion happens in a closed system, the total mass decreases".

Some students think that a precipitate is heavier than a liquid. These students use a naive model of matter dependent on the sensory perception of expecting solids to be heavier than liquids. It is clearly seen that there appears to be a need to further study students' ideas about precipitation reactions.

The above misconceptions are in parallel to those reported by Driver *et al.* (1984), Andersson (1984), and Barker and Millar (1999). The fact that misconceptions prevail among students of the same age in different countries demonstrates the cross-cultural characteristics of the misconceptions.

The evidence presented above suggests that some tenth-grade students have difficulties and misconceptions about the conservation of mass and they do not have well-documented accepted ideas about events occurring in open and closed systems. In this study, the test was implemented with students after they studied the unit on chemical reactions, but the students still held misconceptions. This is in fact not surprising, because chemistry teachers spend only a few lessons introducing the key concepts, such as chemical reactions and the conservation of matter to beginning learners of chemistry. Therefore, many students are not constructing appropriate understanding of such fundamental chemical concepts from the very beginning of their studies. As a result of this, not only do they hold many misconceptions about the key concepts, but also they cannot fully understand the more advanced concepts.

The related literature has a range of reports that indicate students' misconceptions after the instruction (Nakhleh, 1992; Fensham *et al.*, 1995; Gonzalez, 1997; Din, 1998). These misconceptions have been shown to be pervasive, stable and often resistant to change through traditionally organized classroom instruction. They often are being held intact by children and adults even after the completion of formal science instruction (Osborne & Cosgrove, 1983; Osborne & Wittrock, 1983; Hewson & Hewson, 1984; Lee & Law, 2001). Studies on students' misconceptions after instruction are thus important in revealing students' difficulties in conceptualizing new scientific knowledge and suggesting remedies. One of the most fruitful outcomes of the related research is, on the one hand, to alert teachers about students' difficulties in conceptualizing scientific knowledge, and on the other hand, to suggest more effective strategies for improving classroom instruction. The results show that the traditional teaching methods are ineffective, therefore more effective teaching methods need to be developed to help students stop rote learning in favor of meaningful learning.

Because of the role of misconceptions in the learning process, the description, identification, and overcoming of them are of vital importance for science education. Teachers should review, diagnose and think about possible misconceptions or students' prior knowledge, before teaching a class or laboratory in which a new material is introduced. Diagnostic questions can be used in determining students' understanding and misconceptions. Diagnostic tests alone are not adequate for determining the reasons behind the explanations. Clinical interviews can be used to collect more information. By reviewing the possible causes of misconceptions, it is suggested that conceptual development can be promoted by classroom instruction that avoids excessive factual detail, establishes meaningful connections between new and existing concepts, and takes into account students' prior knowledge (Din, 1998). It is also important to design and implement more concept-based chemistry teaching to promote learning of chemistry and to remedy students' misconceptions. Chemistry is a branch of science that should be taught with student centered activities, because it contains many abstract concepts which are difficult to be grasped by students. Therefore, hands on activities, audio-visual aids and demonstrations should often be used in teaching. The key to success is ensuring that students are constructing or reconstructing a correct framework for their new scientific knowledge during the instruction.

Finally, future researchers in this area, in collaboration with teachers and curriculum developers should develop new teaching materials about conservation of matter and implement them in classrooms in an experimental setting, so that they may better understand the effects of different teaching techniques and materials on the misconceptions. Although the related literature indicates that there is resistance towards changing existing conceptions in children's mind, we cannot sit back and wait the misconceptions to be turned into the scientific concepts without any effort. All people involved should work hand in hand and look for ways for remediation, because it is known that while one way of teaching or one type of material is effective in one classroom or laboratory, it may not be so in others. Research done up to now provides some useful information about the type and sources of misconceptions about the conservation of matter, but it has not provided enough information about remediation of different types of misconceptions.

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REFERENCES

Andersson, B. (1984). *Chemical reactions*. EKNA Report No: 12, University of Göteborg, Göteborg.

Andersson, B. (1986). Pupils' explanation of some aspects of chemical reactions. *Science Education*, *70*, 549-563.

Barker, V. (1994). A longitudinal study of 16-18 year old students' understanding of basic chemical ideas. Dphil Thesis, University of York.

Barker, V. & Millar, R. (1999). Students' reasoning about chemical reactions: What changes occur during a context – based post-16 chemistry course?. *International Journal of Science Education, 21*, 645-665.

Ben-Zvi, R., Eylon, B. & Silberstein, J. (1987). Students' visualization of a chemical reaction. *Education in Chemistry*, *24*, 117-120.

Din, Y. (1998). Children's misconceptions on reproduction and implications for teaching. *Journal of Biological Education*, *33*, 21.

Driver, R. (1981). Pupils' alternative frameworks in science. *European Journal of Science Education*, *3*, 93-101.

Driver, R., Child, D., Gott, R., Head, J., Johnson, S., Worsley, C. & Wylie, F. (1984). *Science in schools, age 15.* Research Report No: 2, Assessment of performance unit. Department of Education and Science, London.

Driver, R. & Easley, J. (1978). Pupil and paradigms: a review of the literature related to concept development in adolescent science students. *Studies in Science Education*, *5*, 61-84.

Driver, R., Gott, R., Johnson, S., Worsley, C. & Wylie, F. (1982). *Science in schools, age 15*. Report No: 1, Assessment of Performance Unit. London: HMSO.

Fensham, P. J., Gunstone, R. F. & White, R. T. (1995). *The content of science: A constructivist approach to its teaching and learning.* London: The Falmer Press.

Gilbert, J. K., Osborne, R. J. & Fensham, P. J. (1982). Children's science and its consequences for teaching. *Science Education*, *66*, 623-633.

Gilbert, J. & Swift, D. (1985). Towards a Lakatosian analysis of the Piagetian and alternative conceptions research programs. *Science Education*, *69*, 681-696.

Gonzalez, F. M. (1997). Diagnosis of Spanish primary school students' common alternative science concepts. *School Science and Mathematics*, *97*, 68.

Good, R. (1991). Editorial. *Journal of Research in Science Teaching*, *28*, 387.

Finley, F. N., Stewart, J. & Yarroch, W. L. (1982). Teachers' perceptions of important and difficult science content. *Science Education, 66*, 531-538.

Hackling, M. W. & Garnett, P. J. (1985). Misconceptions of chemical equilibrium. *European Journal of Science Education, 7*, 205-214.

Haidar, A. H. (1997). Prospective chemistry teachers' conceptions of the conservation of matter and related concepts. *Journal of Research in Science Teaching*, *34*, 181-197.

Hashweh, M. Z. (1988). Descriptive studies of students' conceptions in science. *Journal of Research in Science Teaching, 25*, 121-134.

Helm, H. (1980). Misconceptions in physics amongst South African students. *Physics Education*, *15*, 92-97.

Hesse, J. J. & Anderson, C. W. (1992). Students' conceptions of chemical change. *Journal of Research in Science Teaching*, *29*, 277-299.

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

Hills, G. (1983). Misconceptions misconceived? Using conceptual change to understand some of the problems pupils have in learning in science. *Proceedings of the International Seminar on Misconceptions in Science and Mathematics*, pp. 245-256. Cornell University, N. Y.

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

Lee, Y. & Law, N. (2001). Explorations in promoting conceptual change in electrical concepts via ontological category shift. *International Journal of Science Education*, *23*, 111-149.

Lin, H. (1998). The effectiveness of teaching chemistry through the history of science. *Journal of Chemical Education*, *75*, 1326-1330.

Murphy, P. & Gott, R. (1984). *Science Assessment framework*, *age 13 and 15*. Assessment performance unit, Science report for teachers: 2. London: HMSO.

Nakhleh, M. B. (1992). Why some students don't learn chemistry: Chemical misconceptions. *Journal of Chemical Education*, *69*(3), 191-196.

Novak, J. D. (1977). *Theory of education*. Ithaca, NY: Cornell University Press.

Osborne, R. (1982). Science education: where do we start?. *The Australian Science Teachers' Journal*. *28*(1), 21-30.

Osborne, R. J. & Cosgrove, M. M. (1983). Children's conceptions of the changes of state of water. *Journal of Research in Science Teaching*, *20*, 825-838.

Osborne, R. J. & Wittrock, M. M. (1983). Learning science: a generative process. *Science Education, 67*, 489-508.

Paixão, M. F. & Cachapuz, A. (2000). Mass conservation in chemical reactions: the development of an innovative teaching strategy based on the history and philosophy of science. *Chemistry Education: Research and Practice in Europe*, *1*, 201-215. [http://www.uoi.gr/cerp]

Piaget, J. & Inhelder, B. (1974). *The child's construction of quantities*. London: Routledge, Kegan Paul.

Ramsden, J. M. (1997). How does a context-based approach influence understanding of key chemical ideas at 16+? *International Journal of Science Education*, *19*, 697-710.

Stavy, R. (1990). Pupils' problems in understanding conservation of matter. *International Journal of Science Education, 12*(5), 501-512.

Stavy, R. (1991). Using analogy to overcome misconceptions about conservation of matter. *Journal of Research in Science Teaching*, *28*, 305-313.

Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal of Science Education*, *10*, 159-169.

Yarroch, W. L. (1985). Student understanding of chemical equation balancing. *Journal of Research in Science Teaching*, *22*, 449 – 459.