CHEMISTRY AT ELEMENTARY SCHOOLS: PARTICLES OR ALSO ATOMS – THAT'S THE QUESTION

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ABSTRACT

At elementary school level, the description of substances and their changes is preferred by most guidelines of education. If the elementary school includes fifth and sixth graders like in Africa, it seems to be possible to introduce the idea of the Particle Model of Matter to reflect changes of states, dissolving and diffusing processes. As an example the solution of sugar in water can be represented by a mixture of spheres and crosses as in the figure below [1]: one sphere shows a sugar particle, one cross shows one water particle. The only difficulty is the scientific language concerning the original sugar solution, the mental model in the cognitive structure, and the kind of concrete models – may be spheres and crosses or circles with different colors. *[African Journal of Chemical Education—AJCE 7(2), July 2017]*

INTRODUCTION

The introduction of the Particle Model of Matter matches with the famous Chemical Triangle of Johnstone [2]. He points out that we have to differentiate the macro level of substances and their chemical reactions from the interpretation on the sub-micro level by simple particles or by atoms/ions/molecules, and the description by formulae and chemical equations on the representational level (see figure 2). The only way to understand Chemistry is the sub-micro level: without interpretation on the second level, the formulae and equations on the third level must be memorized without understanding. For elementary schools, the first and second level can be realized – the third level concerning formulae and equations should be moved to instruction in junior and senior high schools.

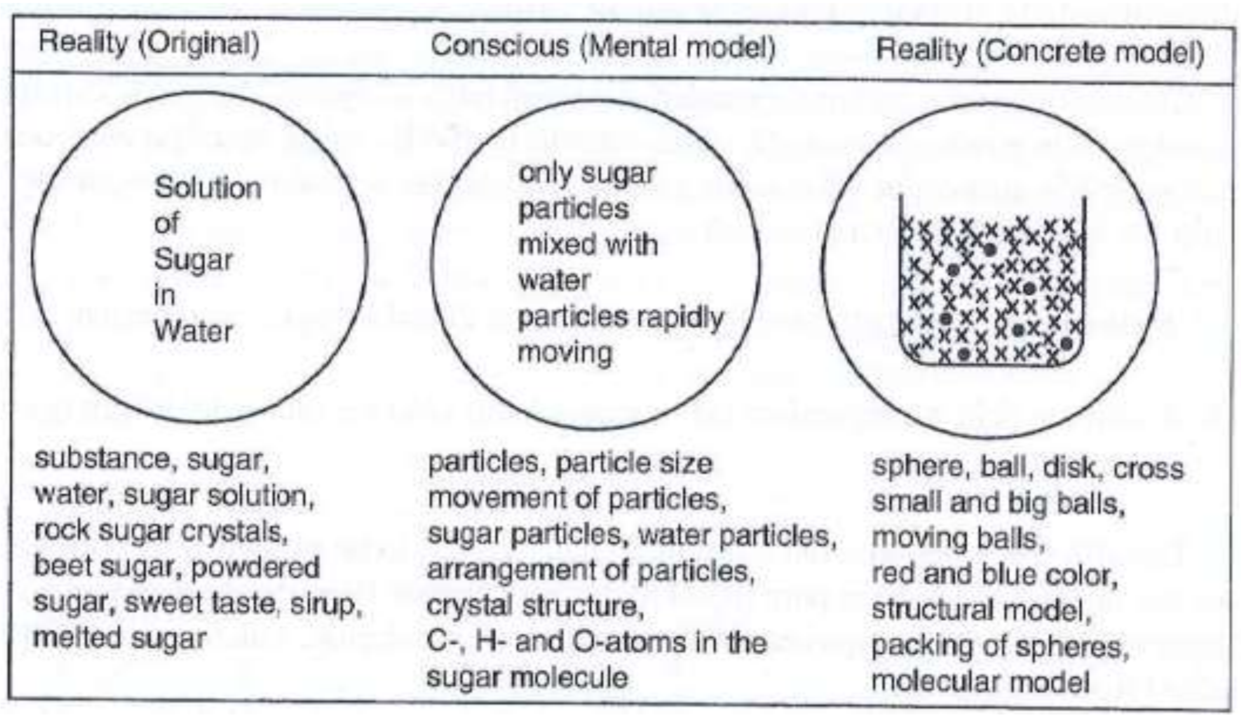

Fig. 1: Terminology on the level of substances, mental models and concrete models [1]

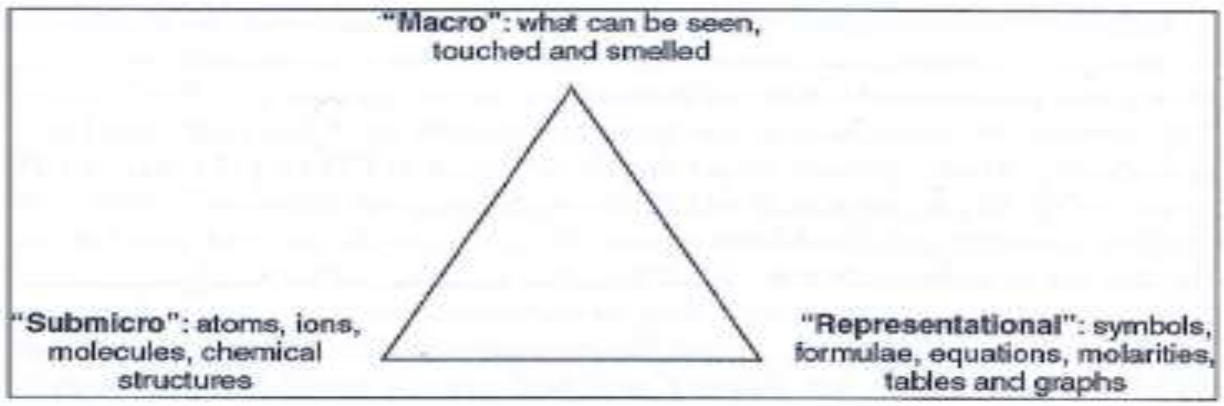

Fig. 2: Chemical Triangle of Johnstone [1]

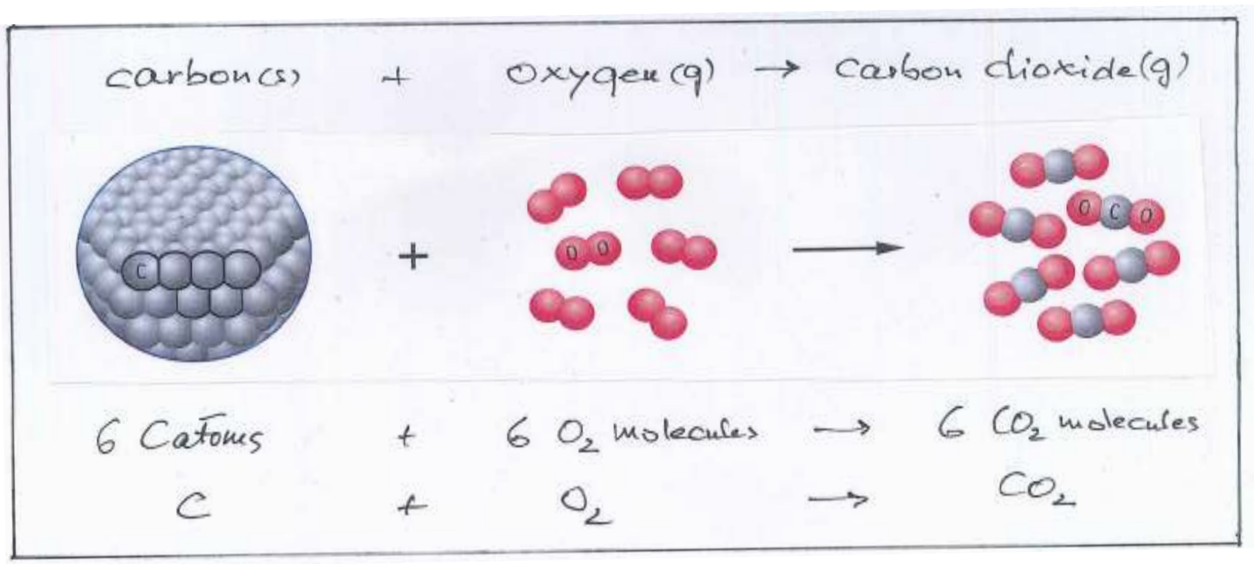

Fig. 3: Interpretation of carbon combustion by Daltons atomic model [1]

The explanation of solution and diffusion processes can be done with the particle model of matter – the explanation of chemical reactions, specially the combustion process, cannot be interpreted with particles. The big question is now if atoms and molecules can be introduced successfully in elementary schools for 5th and 6th graders to reflect the important topic about combustion reactions. One example: if the combustion of carbon will be discussed, you need Daltons atomic model to talk about C atoms, O_2 molecules and CO_2 molecules (see figure 3). It should be teacher's decision if he or she knows the pupils so well that he or she can work successfully with Dalton's model of matter: particles or also atoms – that is the question!

CHEMISTRY FOR LOW GRADES 1 – 3

For pupils of grades 1 – 3, the teacher should show only substances and phenomena of nature, the kitchen and the laboratory: properties of pure substances and their changes by heating with the burner. Dissolving processes may be demonstrated or done by the pupils themselves. The investigation of mixtures and the separation of mixtures to pure substances are easily done and described by every-day language. Some examples:

Phenomena in nature: water evaporation and water steam condensation with discussion of weather phenomena, observing burning processes of wood, coal and fuel – looking to the role of air, discussing sun with heat and light energy, interpretation of photosynthesis processes on a reduced level, looking to pieces of noble metals, ores, minerals, etc.

Phenomena in the kitchen: investigating white powders like sugar, salt, starch, flour and baking powder; boiling and freezing water by observing the thermometer; weighing special portions of flour and sugar, baking and cooking, investigating liquids like milk, oil and vinegar, discussing electrical energy and the transfer into heat by a water-heater or by other cooking facilities; transfer into heat and light by the bulb in a lamp, etc.

Phenomena in the laboratory: melting and boiling temperatures of some pure substances; density of some metals, electric conductivity of metals and salt solutions, dissolving salts until the saturated solution occurs, dissolving gases in water, looking to the mass of 1 L of air (1 L of air weighs 1,3 g); showing the bigger volume of heated gases compared to normal temperature ("coin on the bottle neck, hands on the bottle"), investigating mixtures and separating pure substances, observing energy transfers from the burner to water, etc.

If possible, the young kids should do many experiments by themselves. In that age kids are very curious and really motivated to do something: instead of "chalk and talk", famous experiential learning and learner-centered education should be realized.

If teachers want, the particle model of matter can be introduced in a very simple way (states of matter, solutions) – but normally the concrete models have only a small chance to be understood by those young kids. The proposal of models will follow for grades 4 – 6.

CHEMISTRY FOR HIGH GRADES 4 – 6

The 4 – 6 grades seem to be ready for understanding the mental model that matter is composed of small particles which we can never see: water by water particles, sugar by sugar particles. They also should be ready for taking spheres, coins or crosses as models to represent those particles by a concrete model (see figure 1). They may also be ready for working with Dalton's atomic model: carbon contains of C atoms, oxygen contains of O atoms combined to O_2 molecules, which may react to CO_2 molecules (see figure 3).

1. Particle Model of Matter

The explanation of chemical changes should start with the particle model of matter. Experiments are shown on the macro level and should be interpreted by particles or groups of particles on the sub-micro level (figure 2).

One example by the famous experiment "bottle with jumping coin" [3]. In grades 1 – 3, the pupils have taken an empty bottle (full of air!), given some drops of soap solution on the opening and a coin on it. When pressing the warm hands on the outside of the bottle, the coin starts "to jump up and down" several times. Pupils will explain this observation by the idea that "warm air takes a bigger volume than cold air, the volume increases by heating the air". The 5 – 6 graders will interpret this explanation by the particle model of matter: air particles are moving all the time and occupy a special volume, after heating the bottle air particles are moving faster and the distances increase from particle to particle – the volume becomes bigger than before. Other experiments and model interpretations follow, pupils should discuss and draw their mental model:

a) Heating mixtures of ice and water: watching the thermometer which stays constantly by 0 ^{o}C, ice shows water particles in a regular and symmetric order, energy is used for separating the particles in water which have after heating no order and move fast all the time.

b) Boiling water, measuring the temperature of water and water steam: both temperatures show the same value of 100 ^{o}C. In water the particles are moving all the time but stay together, by heating the distances between the particles grow, the particles are moving faster – water steam takes a much bigger volume than the same portion of liquid water.

c) Dissolving oil and ethanol in water: oil is not soluble in water (but in gasoline), ethanol is very good soluble in every ratio with water, water particles and ethanol particles are moving and mixing together. Distilling red wine: a colorless liquid mixture of ethanol and water comes out, water particles and ethanol particles are separating from pigment particles and other particles of red wine.

d) Diffusion of two gases: a cylinder is filled with brown bromine vapor and covered on the opening by another colorless air-filled cylinder. After some minutes both gases will mix and make a light brown gas mixture, bromine particles and air particles are moving all the time, are colliding and mixing.

e) Making "gold from copper": a mixture of zinc powder and hot concentrated sodium hydroxide solution is prepared (caution – goggles!). A coin with a copper surface is dipped into the solution: the copper turns silvery, "silver is produced". After drying the coin and heating it in a colorless flame, the color of the coin turns golden, "gold is produced". Zinc particles are settling on the coin surface (silvery color), in the heat of the flame zinc particles and copper particles are mixing to a well-known alloy: brass with golden color.

Other experiments may follow which can be interpreted by the particle model of matter. But this model fails if chemical reactions are involved – Daltons atomic model may be introduced and will be able to interpret simple reactions – specially combustion processes.

2. Daltons atomic model of matter

John Daltons big theory of the year 1808 was the connection of well-known elements with the idea of atoms: carbon should be composed of C atoms, copper of Cu atoms, etc. The atoms of one element should have the same mass, different elements are composed of atoms with different masses: m (H atom) = 1, m (C atom) = 12, m (O atom) = 16. The first table of atomic masses came out and Chemistry moved from alchemy to the real science.

The big advantage of Dalton's model is to explain the law of conservation of mass: no atom can be destroyed, no atom can be created, the involved atoms only regroup by reactions (see figure 3): C atoms in the graphite lattice and O_2 molecules of oxygen regroup to CO_2 molecules in carbon dioxide. If the teacher decides to introduce Dalton's model of matter, he/she may show some important atomic symbols (H, C, O, Fe, Cu, S) and some molecular symbols (O_2, H_2O, CO_2) with the help of spheres of different colors and sphere groups for molecules (see molecular model set) or dense packing of spheres for metal crystal lattices. Students will interpret first chemical reactions with the help of their teachers. Examples:

a) Burning pieces of charcoal in a closed flask: 4 – 6 little pieces of charcoal are taken in a 1-L-round flask, which is filled with oxygen. The flask should be closed by an air balloon and weighed. The pieces are heated with a burner from outside. After glowing the flask should be moved around and the coal is burning brightly. After cooling down, the closed flask is weighed again: same mass as before. The gas in the flask is tested by limewater: carbon dioxide. This gas portion weighs the same as carbon and oxygen before: C atoms and O_2 molecules are regrouping to CO_2 molecules (see figure 3).

b) Burning iron wool in an open and closed system. Two big bunches of iron wool (same mass) are hanging at a balance, one bunch should be ignited by a burner flame: this bunch goes down, turns from grey to black color, the mass increases. Another bunch of iron wool is taken in a test tube, which is closed with an air balloon and weighed. With the strong burner, the test tube is heated until the iron wool glows and turns to black color. After cooling down, the test tube is weighed again: same mass. Reacting Fe atoms and O_2 molecules to a crystal lattice of Fe and O atoms can be interpreted with a model drawing (see figure 4). In a closed system, the law of conservation of mass can be shown. The first experiment with an open system shows the increase of mass by reacting oxygen of the air to form black iron oxide.

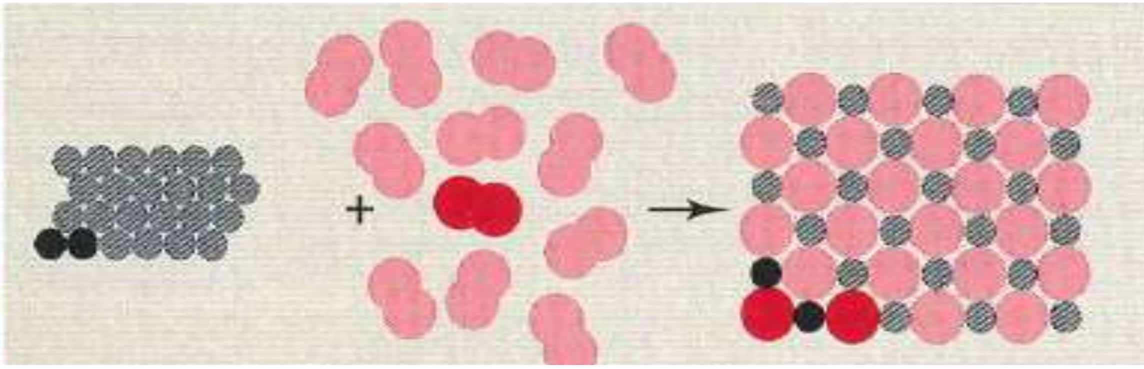

Fig. 4: Reaction of iron and oxygen interpreted by Dalton's atomic model [4]

c) Reacting copper plates in sulfur vapor. In a test tube, sulfur is heated until sulfur melts and the tube is half filled with brown sulfur vapor. The copper plate (about 1 x 5 cm) is heated in the colorless flame and put down into the brown liquid and vapor: the copper glows red and change to a black substance, called copper sulfide. The interpretation can go from Cu atoms in a crystal lattice and from S atoms in the molten sulfur to a regular lattice of Cu atoms and S atoms in copper sulfide (see figure 5).

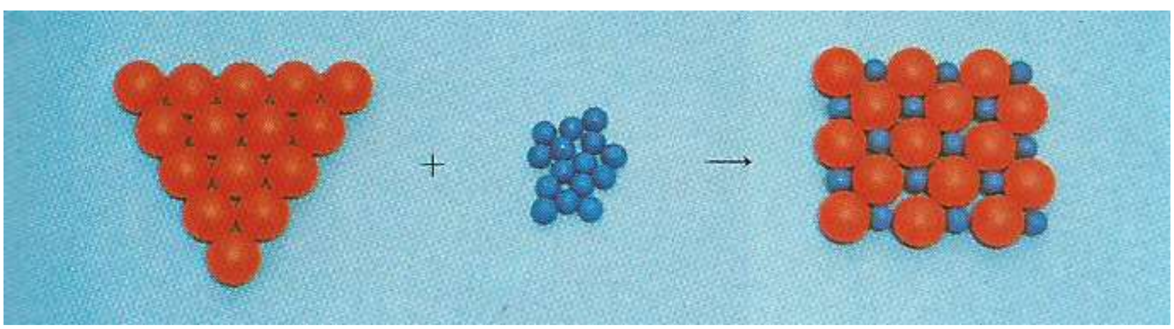

Fig. 5: Reaction of copper and sulfur to copper sulfide [4]

MISCONCEPTIONS OF YOUNG STUDENTS

For some science topics, students are bringing alternative conceptions or pre-concepts or misconceptions which are developed from phenomena in every-day life or by language problems. One example. If all people are mentioning after a big rain and the appearing sun that "water puddles on the street disappear, the sun have taken the water away", the young students develop a distorted concept: "substances can disappear without any rest, they can be destroyed irretrievably". No kid will develop the idea that water evaporates and water steam is mixing with the air, that water particles are moving, escaping from the water surface and are mixing with moving particles of the air.

So science teachers have to challenge those pre-concepts with experiments and concrete models of involved substances. They should give the students the chance for a conceptual change from their mental model to the scientific model. Because the student has developed his or her mental model over years, a conceptual change is not easy: the teacher has to take more experiments and concrete models to change the mental model in the brain of the student – one hour of lecture cannot change the pre-concept, the change needs weeks and months. Otherwise, by the language of people ("after burning charcoal on the grill the charcoal is away"), the pre-concept may occur again.

Sometimes concept cartoons help (see figure 6): concerning the composition of water steam three persons are thinking in non-scientific ways like "water changes to air, to hydrogen gas and oxygen gas", only one person gives the right answer: "it changes to water steam" [5]. For many topics, some misconceptions are observed, and their challenge is offered [6]:

a) "Gases weigh nothing, air is surrounding us, hot air is even going up". Teachers have to show by experiment that 1 liter of air has the mass of 1.3 g, that the air of the classroom can weigh thousands of kilograms, that the atmosphere with the altitude of more than 20 km of air makes a special pressure on us which can be measured by a barometer.

Fig. 6: Concept cartoon concerning evaporation of water [5]

b) "Carbon is after combustion away, is irretrievably destroyed". Students cannot observe the gas oxygen, and cannot see the produced colorless gas carbon dioxide after the burning process. Teachers have to show the reaction of carbon with oxygen, have to prove the formed gas with limewater and may visualize the law of conservation of mass, pointing out that C atoms and O_2 molecules are regrouping to CO_2 molecules of the same mass (see figure 3).

c) "Burning iron wool changes the color from grey to black". Teachers have to realize the experiment with iron wool on a balance to show that oxygen is reacting and forming a new substance – iron oxide. This new substance, iron oxide, has the black color; iron metal is all the time grey and cannot show another color.

d) "Energy is gone". People are discussing their electricity bill and speaking of "used energy which is gone". The students have no chance to discuss that energy cannot be destroyed, that energy can only be transferred from one form to another form: i.e. electrical energy at home can be transformed to light energy and heat energy in the bulb of a lamp.

To challenge the misconceptions, teachers have to do experiments instead of "chalk and talk": experiments convince students, and together with models of matter, the conceptual change can be realized. But it takes time and more experiments and models of the same content – otherwise students stay with their misconceptions and will not discuss scientifically in their future. Teachers have also to pay attention to the language by working with models (see figure 1).

There is especially in Chemistry a "laboratory jargon", which is not helpful for scientific discussions: "water contains of two hydrogens and one oxygen" is sometimes the comment of a chemist. He/she hopes that his/her colleague will understand the "slang" which means correctly: "one molecule of water is composed of two H atoms and one O atom". Experts may stay with the laboratory jargon – for Chemistry education we have to take the scientific terminology: the students are learners and cannot interpret any slang [7].

METHODS OF INSTRUCTION

Presented contents in class are not easy to understand. If the teacher is only presenting the topics, filling the blackboard and asking the students to copy it into their folder, students have a hard work to understand. Students should work themselves with contents and should present their own ideas to explain phenomena. So the teacher has to prepare worksheets or group work to include students in the learning process; he/she should realize learner-centered education. If possible, students may perform their own experiments, may develop their own mental model and build or draw their own concrete model for special phenomena.

1. **Cognitive conflict**

Students should be motivated to think about chemical phenomena – one way is the cognitive conflict. When the teacher burns a piece of iron wool and asks about the mass before and after burning, most students will answer from experiences in every-day life: “after burning the iron wool weighs less than before”. If the teacher takes now two bunches of iron wool at the balance (see 2.c) and shows that the burning bunch gets heavier, students will have a cognitive conflict: “why heavier?”. After long discussions, the reason should be the surrounding air, oxygen as a part of air is reacting to produce black iron oxide, iron oxide weighs more than the bunch of pure iron wool before.

2. **“Think, pair, share”**

For many problems, it is advantageous when teachers give a problem into class and ask students to work first alone and think about an explanation, then to work together as a pair with the neighbor in class, finally some of those pairs present the explanation to share it for the whole class until the right solution is accepted by most of students. After demonstrating the experiment “iron wool at the balance”, students may think alone about the observation “heavier”, then he or she goes together with his or her neighbor to solve the problem as a pair, finally the whole class is sharing the results of the pair work.

3. **Group work**

By working with experiments to show the melting process of different substances, groups of students may investigate different substances. Every group gets a burner, a test tube, a thermometer and a teaspoon of a substance: sugar, salt, sulfur, naphthalene, stearin, etc. The groups try to find the melting temperature and can also look to the thermometer during the melt gets solid: the temperature stays for the time constant when both solid and liquid substances fill a part of the test tube, after all substance is solid the temperature goes down to room temperature. Every group can present their results for the whole class.

4. **Learning stations**

This is another type of group work. When there is a topic with different aspects, different experimental stations can be planned. If salts may be investigated, the teacher can install following stations on different tables in the classroom: melting kitchen salt and sodium nitrate in a test tube (first salt melts at 800 ^{o}C, the other one at about 310 ^{o}C), solubility of salt (how many grams of salt are soluble in 10 mL of water?), separation of salt from ocean water (4 % solution of salt in water should be prepared), density of saturated salt solution (what swims on water and on saturated salt solution?), separation of a mixture of salt and pepper or sand, etc. Student groups have to switch from station to station to learn much about salts, they are motivated by doing experiments themselves, by moving around the classroom and discussing the observations with friends. The role of the teacher is the advisor.

5. **Research**

Because it is not easy to instruct young kids in science, we have to evaluate our steps of education. One research question may be to look which is the most successful way of instruction:

without experiments, with demonstrated experiments by the teacher, with hands-on experiments by students themselves.

When the particle model of matter, is introduced we can compare classes that work with this model and without the model, which work only by talking about particles and those which build or draw models of the observed phenomena. When Dalton's atomic model will be introduced in grades 5 or 6, it is a must to research how they are able to grab the idea of atoms and molecules by special reactions. Because much people are refusing this early introduction, we should have the results of research to convince those people by our facts.

Also the methods can be observed scientifically. Because many teachers like to "chalk and talk" without including discussions with students, we should prove that methods like "think, pair, share", group work and other learner-centered lessons are bringing us more success and also more motivation of students compared to teacher-centered education.

Even motivation can be evaluated by empirical research. If we ask what students like in science or chemistry education, we may find experiments and specially students experiments are very motivating, also investigating things out of the kitchen and out of every-day life motivate students more than working with unknown substances of the laboratory. All these questions can be evaluated by research and empirical investigation.

CONCLUSION

Not many curricula of elementary education propose Dalton's atomic model of matter to explain chemical reactions. If African schools will do it for grades 5 – 6 and will evaluate this way of instruction by empirical research, it will be internationally a big step for modern Chemistry education. But success can only be proved if students work with concrete models like drawings or spatial models of chemical structures for involved substances: students will develop their mental model from concrete models – they will never realize it by "chalk and talk" or only by talking about particles without those concrete models.

All proposed instruction steps are value for student groups in junior or senior high schools: teachers may take the particle model of matter and later Dalton's atomic model. If they do not want to switch from one model to the other, they are also free to skip the particles and come just to atoms and molecules by the atomic model. It is even possible to introduce the existence of ions by an extended atomic model to describe salts, acids and bases correctly by involved ions – we have not to wait for the nucleus-shell model of atoms [8]. When we realize instruction on the sub-micro level, students will understand Chemistry and will be motivated to go on with this interesting science.

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