Doctoral dissertation of Włodzimierz Kuśmierczuk,

Substantive correctness and didactic approach to selected topics in chemistry textbooks for secondary schools and alternative conceptions of students

Abstract

Textbooks and teachers are primary source of students' formal knowledge about chemistry. In the course of learning, students' conceptions should change progressively as they are exposed to additional relevant information in higher grades. For instance, theoretical models used to describe atomic structure and chemical bonds in secondary school are different than at earlier stages. New conceptions relating to electronic structure of atoms and molecules, chemical energetics, kinetics and equilibria are taught mainly from symbolic perspective, the most difficult one for students. They are the core of chemistry knowledge but teaching and learning such complex topics are problematic. It demands using many abstract concepts and students' knowledge of physics is often insufficient. Some teaching devices such as models, analogies, metaphors and anthropomorphisms may be taken literally and lead to students' misconception. The students' ideas may be at odds with those currently accepted by the scientific community. These ideas are called *alternative conceptions* (AC). AC are quite numerous and may be serious obstacles to further learning. Different reasons why students acquire AC are presented in theoretical part of this work.

The aim of this study is to investigate how chemistry textbooks induce students' alternative conceptions (AC) in chosen areas of topics and concepts.

The first part of the research involved analyzing selected contents of chemistry textbooks for advanced level course at senior secondary schools. The study focuses on instances of scientific inaccuracy, didactic approach, coherence of related topics, the instances of insufficient information necessary for proper understanding, as well as vague descriptions that may be ambiguous for students.

Three groups of problems were selected for the analysis:

1. Chemical structure and bonding in quantum mechanical description of electrons in atoms, atomic ions and molecules
2. Chemical reaction energetics
3. Chemical equilibria and chemical kinetics concepts that the textbook authors use to explain some aspects of chemical equilibria or are misused when explaining reaction energetics.

These groups of problems, according to both chemistry teachers and chemistry didactics researchers, belong to the most difficult topics in teaching and cause most students problems.

They are highly abstract (quantum mechanics) or demand a good deal of formal operational thinking (energetics and equilibria). Research conducted around the world has shown that alternative conceptions concerning these problems are abound and similar among students as well as chemistry teachers.

Based on the noticed explicit AC, misleading instructions and faulty definitions in the textbooks, hypotheses were formulated about students' probable AC. Some of these AC were also spread out by some tasks from Matura Examination or mock exam tests offered by educational publishers. The textbooks were probably their origin. The next step involved constructing three misconception multiple choice tests designed to pinpoint students' expected AC. All tasks in these tests were non-computational problems. They refer to the interpretation of concepts and ability to analyze different phenomena. The research carried out over two years covered a group of 192 students from three secondary schools in Zamość.

Test 1. deals with students' misconceptions about quantum mechanical description of electrons, chemical bonds and intermolecular forces. Most of them stem from textbooks authors oversimplification of basic quantum concepts. Atomic and molecular orbitals (*wave functions*) are adopted as two different objects: "orbital area" and "electron cloud". The first concept is of geometrical and the second one of a physical nature. In this conceptual context, hybridization of atomic orbitals and covalent bonds formation as a result of overlapping of such "orbitals" sound strange to students. An electron *quantum state* is defined by four quantum numbers set only, without energy value or any information about how size of orbital domains changes with the atomic number changing. That implies some postulated AC. Unintentional result of reducing atomic orbitals to electron charge domains is that many students perceive some atoms as nonspherical.

Chemical bonds in the textbooks are explained mainly by heuristic octet - doublet rule, not by molecular orbitals or electrostatic interactions. Here, as in the quantum numbers case, physics is replaced by a kind of "magic recipe", and lead to inevitable AC, which are examined in Test 1. Most hypotheses postulated in Test 1. were confirmed.

Test 2. deals with chemical reactions energetics. Textbooks content give students low opportunities (if any) to reason in a coherent way. The exercises consist mainly of calculations based on carelessly defined Hess's law and on provided algorithms. State function and its properties are not defined explicitly with necessary assumptions. There are no references to students' prior knowledge about energetics of atomic processes and chemical bonds. Conditions necessary for meaningful understanding of thermochemistry in evaluated textbooks are not fulfilled. Some of the research results are as follows:

- Only 17.6% of students indicated that heat is a state function only in specific conditions, i.e. correctly interpreted Hess's law.
- Some students think that heat of reaction is related to its rate.
- Some textbook authors, many teachers and hence students are convinced that the sign of a reaction enthalpy can be concluded by observing change of its rate when temperature is being changed.

Test 3. problems are connected with proper interpretation of chemical equilibria. These are particularly numerous and cause many AC. In part, they arise from the complexity of the topics, but some of them can be attributed to the way they are presented in school textbooks. The source of the drawbacks in the textbooks are:

- Definitions of basic concepts such as reaction *reversibility* and the *equilibrium constant* are sometimes faulty.
- Equilibrium when reduced to the kinetic balance only may be a steady-state situation, which is not mentioned in any of the textbooks.
- Basic condition for establishing equilibrium, i.e. isolation of the system, is ignored.
- Relationship between equilibria and reaction rate equations are true for very simple systems only, so kinetic justification of the law of mass action is inconsistent with the students' knowledge about rate equations.
- Kinetic reasoning about chemical equilibrium shift generate many well-known AC.
- The chemical equilibrium control is reduced to the use of the negligently formulated Le Chatalier's rule (RLC). There is no claim in its description that 'stress' should be related to the change of the relevant *intensive parameter*. This last term is not presented in any of the textbooks.
- Phrases like "Write an expression for the equilibrium constant", and the entry that begins with "K = ..." shouldn't be used, because it causes students' unavoidable association "Equilibrium constant depends on the equilibrium concentrations" which is a very common AC.

Research results about the use of RLC show that students use it without analyzing appropriate conditions. They apply the rule even when the phenomenon description excludes equilibrium.

The results of this research can be of help for teachers and authors writing new versions of chemistry textbooks for secondary schools, taking into account that along with another change in the core curriculum for secondary schools, quantum chemistry concepts and thermochemistry will be returning to the school curricula after a few years absence.