Coherence of Physics and Chemistry Curricula in Terms of the Electron Concept

Ivanova Elena
The School of Natural Sciences, Far Eastern Federal University, 8, Sukhanova St. Vladivostok, 690950 Russian Fed.

E-mail: lena---iv@mail.ru

Abstract. One of the major contradictions in subject teaching is the contradiction between the unity of the world and the discrete separated generalized content of natural sciences that study natural phenomena. These are physics, chemistry, biology and more. One can eliminate the conflict if opens the content's interdisciplinary links set by the events that are studied by different disciplines. The corresponding contexts of the phenomenon content arise depending on the discipline, and they are not enough coordinated. Obviously, we need a mechanism that allows establishing interdisciplinary links in the content quickly and without losing the logic of the material and assess their coherence in academic disciplines. This article uses a quantitative method of coherence assessment elaborated by T.N. Gnitetskaya. The definition of the concept of the semantic state introduced by the authors is given in this article. The method is applied to coherence assessment of physics and chemistry textbooks. The coherence of two pairs of chemistry and physics textbooks by different authors in different combinations was calculated. The most cohered pairs of textbooks (chemistry-physics) were identified. One can recommend using the pair of textbooks for eighth grade that we offered that favors the development of holistic understandings of the world around us.

1. Introduction
Studying natural sciences such as high school courses of physics, chemistry and biology should facilitate forming an integral perception of the scientific picture of the world; understanding of connectedness and correlation of natural sciences. That’s why it’s significant to have a mechanism which allows establishing interdisciplinary links in different subjects.

Nowadays there are a lot of textbooks in which different authors describe a course of physics. Surely, these textbooks vary both in order of chapters and materials included. One could say the same about chemistry textbooks. Obviously, it raises the questions: how fully do contents of physics and chemistry textbooks correspond with each other and do the connectedness of contents of physics and chemistry textbooks by different authors differ? The answers may be found if we calculate a degree of coherence for pairs of chemistry and physics textbooks in different combinations using the quantitative method of interdisciplinary links graph model worked out by T.N. Gnitetskaya. [6,7].

2. Coherence of high school courses of physics and chemistry on the basis of interdisciplinary links graph model.

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For analysis we select two physics courses for 7-9th grades: (Physics-1) by A.V. Peryshkin [2], (Physics-2) by S.V. Gromov, N.A. Rodina [3]; and two chemistry courses for 8-9th grades: (Chemistry-1) by O.S. Gabriyelyan [4], (Chemistry-2) by R.G. Ivanova [5], described in the appropriate textbooks. The chosen textbooks are on the federal list of textbooks recommended for use in the process of learning at the educational institutions by the Ministry of Education and Science of Russian Federation. At the first stage of analysis we build four spaces of interdisciplinary content: Physics-1 with Chemistry-1; Physics-2 with Chemistry-1; Chemistry-1 with Physics-1; Physics-2 with Chemistry-2.

At the second stage of analysis we calculate quantitative characteristics of interdisciplinary links on the basis of the method suggested in [8,9]. The values of interdisciplinary links length and strength obtained for these chemistry and physics courses build the hierarchical sequence. The hierarchy of physics course’s concepts which are used in chemistry course includes, first of all, the fundamental concepts. It’s meaningful that the list of fundamental concepts for physics is similar both for Chemistry-1 and Chemistry-2. Calculation of quantitative characteristics of the interdisciplinary links graph model (relative maximal length L and relative connection strength С) [6,7] enables to establish the hierarchical sequence of physical concepts where an interdisciplinary fundamental core of physics and chemistry composes physical concepts which relative maximal length L is equal L = 1 and relative connection strength C lies in the interval of 1,00 ≤ С ≤ 0,73.

At the third stage of analysis we calculate a degree of coherence between the chosen chemistry and physics courses [6,7]. The coherence of two courses is regarded as the sum of all interdisciplinary links graphs’ strengths for a set of knowledge elements. This article deals with the coherence of physics and chemistry for the group of concepts which is regarded as the calculation of sum of all graphs’ strengths of direct interdisciplinary links for the set of physics knowledge elements used at the chemistry course or the set of chemistry knowledge elements used at the physics course with the reverse direction of interdisciplinary links.

Table 1 Forest of orgraphs of interdisciplinary links for physics and chemistry established using the electron concept in chemistry course for 8-9th grades by O.S. Gabriyelyan

| Structure of chemistry course | Elements of physics course | Group of concepts | Relative max. length L | Connect ion relative strength С |
|-----------------------------|---------------------------|-------------------|------------------------|-------------------------------|
| Atoms of chemical substances | Compounds of chemical substances | 8th grade | 1 | Electron | 1,00 |
| Chemical reaction rates. Chemical equilibrium | Solubility. Solutions. Ion-exchange reactions and redox reaction | 9th grade | 2 |
| Introduction. Overview of chemical substances | Metals | 3 |
| Nonmetals of subgroups VI- VII A | Nonmetals of subgroups IV-V A | 4 |
| Organic substances | | 5 |
| | | 6 |
| | | 7 |
| | | 8 |
| | | 9 |

For instance, with the physical concept of electron from physics to structural elements of chemistry course for 8-9th grades by O.S. Gabriyelyan eight links are built between the following structural elements of chemistry: 1) Atoms of chemical substances; 2) Compounds of chemical substances; 3) Solubility. Solutions. Ion-exchange reactions and redox reaction; 4) Introduction. Overview of chemical substances; 5) Metals; 6) Nonmetals of subgroups VI - VII A; 7) Nonmetals of subgroups IV-V A; 8) Organic substances. They compose a forest containing eight orgraphs.

The described analysis of interdisciplinary content of high school chemistry and physics courses shows the most significant, relevant to both subjects’ concepts, such as: an atom, a molecule, an electron, a substance and others.
It may be useful to take the obtained results into consideration while choosing chemistry and physics textbooks. Thus, for those who learn physics with A.V. Peryshkin’s textbook, chemistry textbook by O.S. Gabriyelyan may be recommended. When learning physics with the textbook by S.V. Gromov, N.A. Rodina, chemistry textbook by R.G. Ivanova may be useful for grades studying the general course of chemistry.

3. Semantic states of a physical concept.

One of the major goals of secondary school is to develop a holistic unity of the World around us. This goal may be achieved during the process of natural disciplines’ studying on the interdisciplinary basis. The content of the concept expands and its meaning is transformed in the process of studying the courses. However, the volume of information in the concept increases while transferring from the previous meaning to the following one. Let us introduce and formulate the term “semantic state” of a term, which is identical to the “meaning” of a term.

Semantic state of a concept is the state of its content, which serves to form one of the concept’s meanings completed at the given stage of studying, and possessing the required informational features. Then the process of concept formation can be viewed as a process of transfer from one semantic state to the other [8].

Two paragraphs of the 8th grade chemistry course contain eight semantic states of an electron (a particle of atom which transfers electricity, free electron, the lowest negative charge equal to “-1”, a structural unit of atom, a part of the atom planetary model, an element of electronic shell, a structural unit of atom with defined energy, an electron of external atomic level). Moreover, the study period of these meanings of electrons in chemistry does not coincide with the time of studying this concept in physics. Electrons are studied 13 weeks later in the selected course of physics. Three paragraphs are devoted to forming of the concept “electron”; these paragraphs describe three semantic states of the term (a negatively charged particle, an atomic structural unit, free electron).

At first sight, it is possible to find corresponding semantic states of the term “electron” in chemistry to all three semantic states of this term in physics. However, their semantic contents differ.

- a negatively charged particle, a structural unit of atom, a free electron.
- an atom particle that transfers electricity, a free electron; the lowest negative charge equal to “- 1”, a structural unit of atom; a part of atom planetary model; an element of electronic shell, a structural unit of atom with defined energy, an electron of external atomic level.

For example, the first semantic state of the concept “electron” as a negatively charged particle in physics has a similar definition in chemistry as well. However, the course of physics says that an electron has the lowest negative charge and provides its quantitative value and measurement units; the course of chemistry does not take that into consideration and describes an electron as having a negative charge equal to “-1”. It is surely possible to explain this discrepancy by an attempt to ensure a more convenient description of the topics such as “Degree of oxidation”, “Oxidation-reduction reactions” and others. Nevertheless, the ambiguity of concept definitions used in academic courses and lack of connections between these two definitions result in confusion thus complicating the process of studying these fundamental concepts.

This dramatic difference is caused by the fact that in chemistry the concept “electron” as an atomic structural unit is formed based on the experiments by Thomson and Rutherford who have their own arsenal of concepts, for example α- и β-particles, γ rays, radioactivity (introduced to explain the experiment of Becquerel). However, neither these experiments nor the concepts related to them are used in the chemistry course for 8-9th grades again, but they overload the content of the paragraph and there are doubts about the practicability of structuring the course in this manner. Besides, the graph of structure of the concept “electron” from the chemistry course contains three additional semantic states of the concept “electron” (an atom particle, which transfers electricity, a free electron, the lowest negative charge equal to (-1)) that are obviously unnecessary as the physical structure shows (contains only one additional semantic state of the concept “electron” as a negatively charged particle).
In order to reduce the volume of information, a detailed description of the Rutherford's experiment could be removed from the chemistry course while forming the fourth semantic state of the concept “electron” as a structural atom unit. Some of the remaining semantic states in the course of chemistry and physics for 8th grade are not used again, for example the concept of electron as a part of the atom planetary model.

4. Summary
Therefore, the problem of breaking in knowledge which is one of the main reasons of complexity to percept physics and chemistry may be solved with involving preliminary coherence assessment of disciplines’ courses on the basis of the quantitative method of interdisciplinary links graph model. Good coherence of physics and chemistry courses assure developing an integral perception of natural phenomena for pupils and in its turn facilitates more effective learning of natural sciences and the educational process in general. Structuring content of physics and chemistry courses by defining semantic states of fundamental concepts, for example, an electron, helps to build integral and obvious inter-subject links between the chosen connected courses.

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