Modeling the Interdisciplinary in the Process of Training Physics

Tatyana Gnitetskaya¹, Elena Ivanova², Larisa Dubovaya³, Yuliya Shutko⁴, Natalya Kovalchuk⁵, Elena Karnaukhova⁶

¹-⁶The School of Natural Sciences, Far Eastern Federal University, 8 Sukhanova St., Vladivostok, 690950, Russia

E-mail: gnitetskaya.tn@dvfu.ru

Abstract. The information model of interdisciplinary links (Gnitetskaya T., 2016) allows to reach the interdisciplinary in the process of training physics. Presenting the fundamental physical term with semantic structure we can see that structure’s node(s) where interdisciplinary link(s) from physics to chemistry and vice versa could be established. Method of optimization the interdisciplinary content was described in this paper. Method based on quantity estimation of the information – an entropy, as characteristic of semantic structure graph. Results of entropy calculation for interdisciplinary content of term “atom structure”, corresponded to school physics’ level, were discussed.

1. Introduction

Although the problem of increasing the interdisciplinary of educational material of such adjacent disciplines as Physics and Chemistry has been discussed for a long time, it still attracts universal interest. Multiple models have been developed and applied in the area of interdisciplinary research; however, all of them are qualitative. Qualitative models are easily available and can be applied to the interdisciplinary content thus proving their indisputable advantage. At the same time, introduction of interdisciplinary information into the educational material substantially increases its volume. Unfortunately, a qualitative model fails to evaluate the increase of educational information. Striving for the interdisciplinary content without restricting its volume poses a serious threat of overloading the students with information.

As a complex informational system, a human has at least three restrictions on transforming information. They involve restrictions in sensitivity, resolving power and carrying capacity. Carrying capacity is a maximal speed of transmitting information in a channel; it is measured in bps (bits per second) [2]. The greater the carrying capacity of a communication channel is, the bigger volume of information it can transmit per a time unit.

Carrying capacity of a human communication channel depends on its type. Thus, an optical channel can perceive and process 10⁷ bps, thermal – 5*10³ bps, vestibular – 13 bps. The communication channel that transmits semantic information to consciousness has a carrying capacity of 16 bps. [7,8] (according to other sources - 100 bps) [9].

Theoretical restrictions on the carrying capacity in the theory of information are determined by the Shannon theory [5] that proves that if a channel has a capacity of P, then the amount of removable

¹ To whom any correspondence should be addressed.
uncertainty cannot exceed this value. In addition, according to the Ashby’s Law of Requisite Variety, “the necessary choice is absolutely dependent on transmission of, at least, an equal amount of information”. The possibility of applying the principles of information theory to describing the processes of information perception by consciousness has been studied by a research team from the RAS Institute of Psychology; the research, headed by B.F. Lomov, has been described in the paper [4]. These facts show an existing restriction of information perceived by consciousness; neglecting these restrictions results to the real danger of information overloads.

In this context, the interdisciplinary content can be modeled and optimized via an informational model of interdisciplinary links [1,3]; the qualitative features of this model allow evaluating the rate of content entropy growth in case of adding interdisciplinary information.

2. **Informational model of intradisciplinary links.**

The parameters that characterize the informational content of a portion of material are calculated via the method of semantic structures described in [1,3,10]. The method of semantic structures relies on the structuring of educational material (module, theme as part of the concept theme) with subsequent representation as a semantic structure graph, as well as on the calculation of information contained in this structure and the minimal time for acquiring it.

The semantic structure model of any portion of content has a hierarchic structure (refer to picture 1). Groups of semantic units that belong to the lower levels of the graph are connected with the semantic unit that lies at the following, higher level. The top of the graph contains the knowledge element with a semantic content reflected by the structure.

The graph reflects the collateral subordination of semantic elements in the structure. It registers their arrangement with levels and defines the degree of the structure’s organization. The degree of abstraction calculated within this model characterizes the degree of semantic structure’s organization. Semantic units located in the nodes of the graph are the corresponding elements of knowledge (laws, theories, concepts, etc.), abilities and skilled included into the modeled portion of the content with the links represented by interdisciplinary connections. Informational characteristics of the model includes the volume of semantic information contained in the content portion, building the structure, as well as the coefficient of relative entropy that together represent the characteristics of both the quantity of information and the configuration of semantic units and interdisciplinary links in the structure, thus characterizing the complexity of the educational material content subject to research.

Construction of the semantic structure of a content portion starts with defining all concepts (physical, mathematical, etc.) contained in this structural element. The lower level of generalization holds the concepts that have been studied before (in the previous paragraph, section, different academic discipline, or introduced in this paragraph); the following level of generalization contains the concepts including the ones located below, and so on up to the top of the graph that holds the concept which is under study in this portion. One portion can carry several graphs; their amount is determined by the quantity of concepts that are studied in it.

In this article, we are going to show how changes in the paragraph’s content can influence on the qualitative characteristics of the informational models of interdisciplinary links, in particular on the volume of information contained in the content of a Physics textbook paragraph and its entropy. We are also going to suggest a method of optimizing the interdisciplinary information based on the example of a very important interdisciplinary theme “Atom structure” studied in the 8th grade course of Physics of the high school.

3. **Entropy as a criterion of optimizing the content of interdisciplinary information**

The content of this theme definitely covers the concept of electron introduced within the course of Chemistry and Physics. The sequence of courses is such that the concept of electron in its various semantic states is introduced in the first paragraphs of the 8th grade Chemistry textbook. We have mentioned the semantic states of concepts in the work [6, 10] suggesting eight semantic states of electron introduced in the Chemistry course – ranging from the first one, which defines an electron as
an atom particle that carries electricity to the eighth one where the concept means an electron of the external atomic level.

Figure 1. Semantic structure of the fourth semantic state of electron as a structural atom unit, as introduced in the 8th grade Chemistry course.

The course of Chemistry starts with describing the structure and composition of an atom. The course of Physics introduces the concept of atom much later. It is logical to reduce the content of Physics by relying on the concepts already introduced in Chemistry. That is what the authors of the reviewed textbook do. However, there are no references to the paragraphs with necessary material in the Chemistry textbook. Lack of indication of the existence of interdisciplinary connection is a serious oversight that makes perception of the interdisciplinary topic more challenging.

The same topic of Physics introduces the concepts of electron in two semantic states - as negatively charged unit and as a structural unit of an atom. The first statement relies on the Millikan’s experiment; the second is described via a planetary model for atoms of hydrogen, helium and lithium without describing the Rutherford’s experiment. Perception of these abstractions is extremely complicated. Much more information than contained in the theme is required in order to form a consistent understanding of the atom structure. It is reasonable to establish interdisciplinary connections with Chemistry where the fourth semantic state of electron as atom’s structural unit has already been studied. Picture 1 describes the corresponding semantic structure of electron in this semantic state included into the Chemistry course. It is obvious that the structure has 11 levels of abstraction; its final elements are located at different levels. Configuration of the structure is very complex. Author of the Chemistry textbook has considered it necessary to describe the experiments of Thomson and Rutherford that require the knowledge of cathode rays, alpha- and beta- particles while introducing an electron as a structural unit of atom. This information into the 8th grade Physics course can be added in two places on the graph of the semantic structure in the topic of atom composition in paragraph 30 in the 8th grade Physics textbook. The first link is possible in node K_1, where the second
semantic state of electron in Physics is introduced. The graph of semantic structure of this kind of presentation of an interdisciplinary topic is shown on Picture 2.
atom; $K_7$ – Model of helium atom; $K_8$ – Model of lithium atom; $K_9$ – Atom is neutral (number of protons equals to the number of electrons); $L_1$ – Atom; $L_2$ – Atom model; $M_1$ – Atom composition.

**Figure 2.** Semantic structure graph of the topic “Structure of atoms” in the 8th grade course of Physics with the first method of adding interdisciplinary information from the course of Physics.

As we have mentioned before, this section of 8th grade Physics content of this author has a significant gap in the grounds that are available in the course of Chemistry. Therefore, the link is quite reasonable. Another place where the link can be established is congruent to the nod $K_1$ (Fig.2), which introduces the first semantic state of atom in Physics in the planetary model concept but without describing Rutherford. The second variant of the topic’s graph structure with interdisciplinary information related to nod $K_1$ (Fig.3) is shown on Picture 3. This combination of interdisciplinary information of Chemistry and Physics will allow connecting the Rutherford’s experiment described in the Chemistry course with the planetary model of atom in the course of Physics.
It is obvious that one interdisciplinary material should not be discussed twice within one topic. Therefore, it has to be decided in which of the two places an interdisciplinary connection should be established. The answer to this question will be obtained if the entropy equivalence degree of the two variants of interdisciplinary connection is established. Our method of defining the informational characteristics of semantic structure graphs allows calculating the square of information entropy contained in the structure.

4. Conclusions

Table 1 shows the values of informational characteristics of semantic structure graphs, including the square of entropy, calculated for the two cases of adding interdisciplinary information from the 8th grade Chemistry course into the Physics course of the same grade.

Table 1. Informational characteristics of semantic structure graphs for the two methods of presenting interdisciplinary information.

| Method | Square of entropy $S^2$ (Kb$^2$) |
|--------|----------------------------------|
| 1      | 1792                             |
| 2      | 1637                             |

The table shows that the first method of presenting the interdisciplinary topic “Structure of atoms” has a bigger value of entropy square than the second method: 1792 Kb$^2$ for the first method, and 1637 Kb$^2$ for the second one respectively. Thus, without changing the volume of interdisciplinary information, we can influence on and optimize the content entropy by choosing the optimal place of including the...
interdisciplinary information. This approach can help in compiling interdisciplinary courses while avoiding overloads.

References
[1] Gnitetskaya T.N. 2016 The entropy estimation of the physics' course content on the basis of intradisciplinary connections' information model (Journal of Physics: Conference Series) V. 738(1)
[2] Yaglom A.M. 1973 Probability and information, Moscow, 511
[3] Gnitetskaya T.N. 2015 Information Model of Intradisciplinary Connections in the Context of a General Physics Course (Proceedings 2015 International Conference on Simulation Modeling and Mathematical Statistics) Pp. 271-275
[4] Lomov B.F. 1966 Humans and Technology. Articles on engineering psychology, Moscow, 464
[5] Shannon C. 1963 Works of theory of information and cybernetics, 830
[6] Gnitetskaya T.N, Ivanova E.B. 2012 Semantic status of chemical concepts (Advanced Materials Research) Volume 550-553, 2012, Pages 3429-3432
[7] Frank H. 1962 Kybernetische Grundlage der Pädagogik, AUGTS – Verlag Baden – Baden, Gauthier – Villars Editeur, Paris
[8] Klaus G. 1966 Kybernetik und Erkenntnistheorie, VEB – Deutschr Verlag der Wissenschaften, Berlin 28, 175
[9] Steinbuch K. 1963 Menschen oder Automaten im Weltraum? - “Natur-wissenschaft. Rundschau,” 16, N 9, C. 341–349
[10] Gnitetskaya T.N., Ivanova E.B. 2006 Method of semantic structures in the academic process. (Chemistry in school) v.No7, Pp. 45-49