Modeling Interdisciplinary Notion “Substance” with Information Model

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Abstract. Wireless mobile technologies have caused a tendency to use mobile devices in the learning process. However, delivery mode should be changed. This paper describes a method of uploadable semantic structures for students’ personal mobile devices that would ensure interdisciplinarity.

1. Introduction

Disciplinary education, evolving behind the sciences, contains subjects under names coinciding with those of the sciences and preserves specific features of descriptive framework pertinent to each of the sciences. Although nature is a common research subject for natural sciences, while explaining the same natural phenomena each of natural sciences uses different terminology and different theoretical methods of description. Different conceptual frameworks translated into contents of school subjects, such as physics and chemistry, results in student hesitation, or sometimes even inability to identify the same natural phenomenon discussed within courses in different disciplines.

Back in the XIX century, physics and chemistry competed for the title of a fundamental science with a theoretical basis offering groundwork for interpreting experiments conducted within the scope of other sciences. Both had short odds for being called a fundamental science, when quantum mechanics came around to explain an atomic model. Since then, physics has been enjoying its status of an absolutely fundamental science. However, nomenclatures of chemistry and physics courses vary enormously.

The issue of content interdisciplinarity goes back decades and has been a challenge for many famous researchers. In the 1960s, the Soviet Union awarded a public tender for investigation of interdisciplinary links. Under the contract, pedagogical community led by Institute of Pedagogics with the USSR Academy of Sciences performed a tremendous research to define properties, features and functions of interdisciplinary links [1], and to develop interdisciplinary maps and recommendations for teachers [2]. Yet, contents of textbooks on physics and chemistry remained the same, thus bringing the work done almost to naught. Today, authors of new textbooks on chemistry aim to refer to rendering certain issues in physics. However, the efforts prove to be insufficient for providing students with an insight into an integral notion of the surrounding world.

«Nature» devoted a special issue to interdisciplinarity. Authors of the journal articles ended in discussions on the importance of interdisciplinarity in a modern world. Mind Meld (Nature 2015, 289–

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290) introduced the reader to the issue of interdisciplinarity. The article asked what interdisciplinary science was and proposed that, regardless of anything else, it would be a synthesis [3]. Integration of social science into research is crucial (Nature 525, 291) noted the disconnect between research and the general public, and called for the integration of social sciences into research projects to best represent that public [4]. Why interdisciplinary research matters (Nature 525, 305) demanded that hard and soft sciences work together to solve big social issues, and noted the pros, cons and difficulties addressed in the other articles in the issue [5]. Interdisciplinary research by the numbers (Nature 525, 306–307) acknowledged that interdisciplinarity was difficult to define, and presented citation research to demonstrate growth in interdisciplinary work [6]. How to solve the world's biggest problems (Nature 525, 308–311) claimed that large complex problems required a response from more than one discipline and that different skill sets must be assembled [7]. Grant giving: Global funders to focus on interdisciplinarity (Nature 525, 313–315) noted disciplinary resistance to collaboration, but pointed out three advantages to such sharing, mostly relating to complexity and liminality, and noted increases in global funding for such work [8]. Interdisciplinarity: How to catalyse collaboration (Nature 525, 315–317) noted disciplinary conflict and proposed the exploitation of five principles for interdisciplinarity (sharing, engaging difference, dialogue, support, and bridging), which were successfully tested in an institute [9].

2. Information Technologies and Information Model of Interdisciplinary Links

The main reason why Russian teachers neglected the results of the interdisciplinarity study was lack of tasks with interdisciplinary content in the textbooks, for students to analyse in class, or ponder over independently, or refer to sometime later and use for other educational objectives.

Introduction of wireless technologies into every sphere of human activity enhances possibilities for education and allows for a new solution of the old interdisciplinarity issue. Modern school students draw large amounts of information upon networks using their gadgets. They are embarrassed with neither fine print on a device display, nor intricate search for the information required. Moreover, teenagers have good understanding of search semantic hierarchy, like “follow a link”, and they are not surprised to find plenty of information in a word, which can be conveyed by other words. The above circumstances produced an idea to represent content of a paragraph in a mode that would be readily accommodated by a student’s phone display and stay at hand. Naturally, this would be interdisciplinary information provided with a path to where it could be used in the course of study.

To implement our idea, we exploited in information model of interdisciplinary links developed by T.N. Gnitetskaya [10].

A link is a philosophical category, which allows setting a comparison criteria for system elements and performing assessment of the category entirety. One of the varieties of links outlined in philosophy is a "substrate providing transfer of information.... This interpretation of a link is the basis of the interdisciplinary link information model, which is based on an interdisciplinary link graph model developed by the author. The interdisciplinary link graph model is a directed graph tree built between an element of the structure where this notion (or the law, or other element of knowledge) is introduced and an element of the structure where this concept (or other element of knowledge) is used. In fact, the intradisciplinary link graph model, where graph nodes are represented as semantic structures, updated by the calculation of informational characteristics, is considered by the author as an intradisciplinary link information model.

3. Substance as an Object of Interdisciplinary Link between Physics and Chemistry

Before you begin to Physics is a science about nature which introduces us to a wide range of types of substances. Meanwhile, chemistry is a science about substances. Not only the notion of a substance is characterized by high interdisciplinarity (used in contents of both physics and chemistry), but it also has a deep philosophical meaning. Being one of the matter species, a substance underlies the world structure. Therefore, it is critical, from methodological perspective, to provide students with a global view of a substance. Knowledge about a substance can be deepened and strengthened through wireless technology in the following way. We suggest shaping the data bank on a substance contained in textbooks on physics and chemistry into semantic structures [11]. The semantic structures can be
handed out to students in physics and chemistry classes addressing a substance, and relied upon for
covering the topic. The structures emphasize the nodes where a link can be executed to another
discipline through a semantic state [12] of the notion of a substance. Structures for relevant semantic
states of the notion of substance are distributed by the teacher among the students, e.g. within a
dedicated Whatsapp Group. A task for the students is to insert a structure of the required semantic
state of a substance studied in physics class into a structure related to a substance
addressed in chemistry classes to independently identify the interdisciplinary kink and comprehend the
integration of meanings of a substance within the contents of physics and chemistry.

The article illustrates the semantic structures by the notion of a substance introduced in the
beginning of the chemistry course by O.S. Gabrielyan (8th grade, paragraph 2) The semantic states that
the notion of a substance takes on in physics and chemistry were isolated from the contents of
textbooks on physics and chemistry by N.S. Purysheva and above mentioned O.S. Gabrielyan. These
books have been analyzed in our previous work [12, 13], and their contents were shown to have an
adequate level of correlation.

**Table 1.** Semantic states of the notion of a substance in physics and chemistry courses

| Physics  | Chemistry |
|----------|-----------|
| Substance\textsubscript{1\text{ph}} | As one of the matter species | § 1, 7th grade |
| Substance\textsubscript{2\text{ph}} | As what physical bodies consist of | § 1, 77th grade |
| Substance\textsubscript{3\text{ph}} | As what inert physical bodies with certain density consist of (certain substance) | § 18, 7th grade |
| Substance\textsubscript{4\text{ph}} | As what consists of particles with spaces between them | § 2, 8th grade |
| Substance\textsubscript{5\text{ph}} | As what consists of the same atoms and molecules (certain substance) | § 3, 8th grade |
| Substance\textsubscript{1\text{ch}} | As what physical bodies consist of (reference to physics) | § 2, 8th grade |
| Substance\textsubscript{2\text{ch}} | As what consists of molecules, molecules consisting of atoms (reference to physics) | § 2, 8th grade |
| Substance\textsubscript{3\text{ch}} | As what consists of atoms and molecules and possesses certain physical properties | § 2, 8th grade |
| Substance\textsubscript{4\text{ch}} | As a molecule having a mass equal to the sum of masses of the chemical elements comprising the substance | § 6, 8th grade |

A fragment of the list of semantic states of the notion of a substance is given in Table 1, which
shows that the semantics introduced in the physics course is used in the chemistry course. For instance,
one of the initial interpretations of the notion of a substance in the physics course correlates with its
second semantic state in physics: “substance\textsubscript{2\text{ph}} as what physical bodies consist of”. This is the
meaning used to introduce the notion of a substance in the chemistry course, while covering
molecules and atoms helps broaden the meaning to the second semantic state in chemistry:
“substance\textsubscript{2\text{ch}} as what consists of molecules, molecules consisting of atoms”.

**4. Results and Discussion**

Fig. 1 shows a semantic structure graph for the notion of a substance in its second semantic state in
chemistry as mentioned above. An interdisciplinary link is established in nodes D\textsubscript{1} and D\textsubscript{2}, wherein
structures from physics must be ins
ered. It should be noted that in class, instead of the graphs students work with structures with the
same number of nodes and links, but with notions specified in the nodes. For instance, Fig. 2 shows a
semantic structure of the notion of a substance second semantic state in physics. Semantic structure of
a paragraph is built up as follows: all physical concepts are picked up from the paragraph; the concepts
are then placed onto the hierarchy levels so that the most simple ones, or those carried forward from
previous paragraph, reside on the first level followed on upper levels by those with meaning formed by notions from the lower level(s), and so on, up to the top of the structure where a concept from the paragraph title resides.

| Notion | Level |
|--------|-------|
| A_1 – type of atom, A_2 – atom, A_3 – neon, A_4 – argon, A_5 – krypton, A_6 – helium, A_7 – two atoms of hydrogen, A_8 – one atom of oxygen, A_9 – atom^{1}_{oxygen}, A_{10} – type of atom, A_{11} – oxygen, A_{12} – hydrogen, A_{13} – carbon, A_{14} – oxygen, A_{15} – carbon, A_{16} – oxygen, A_{17} – hydrogen, A_{18} – carbon, A_{19} – type of atom, A_{20} – atom^{1}_{oxygen}, B_1 – chemical element^{1}_{ch}, B_4 – inert gases, B_5 – hydrogen light gas (H_2), B_6 – iron, B_7 – oxygen gas (O_2), B_8 – aluminum Al, B_9 – copper Cu, B_{10} – water, B_{11} – chemical element, B_{12} – starch, B_{13} – carbon dioxide CO_2, B_{14} – sugar, B_{15} – light gas, B_{16} – density 9*10^{-3} \text{ g/cm}^3, B_{17} – t_{boil} = -253^{3} \text{C}, B_{18} – t_{melt} = - 259^{3} \text{C}, B_{19} – colorless, tasteless, odorless, B_{20} – light weight, B_{21} – strength, B_{22} – light weight, B_{23} – high electrical conductivity, B_{24} – non-poisonous, B_{25} – plasticity, B_{26} – non-poisonous, B_{27} – high heat conductivity, C_1 – body composition, C_2 – glass, C_3 – water, C_4 – test tubes, C_5 – flasks, C_6 – glasses, C_7 – bottles, C_8 – chemical element^{1}_{ch}, C_{9} – free hydrogen atoms on the Sun, C_{10} – (O) oxygen atom, C_{11} – atoms of the same chemical element, C_{12} – atoms of different chemical elements, C_{13} – example H_2, C_{14} – color, odor, gloss, C_{15} – density, C_{16} – hardness, C_{17} – plasticity, C_{18} – solubility, C_{19} – boiling temperature, C_{20} – melting temperature, C_{21} – heat-, electrical conductivity, C_{22} – aircraft and missile engineering, C_{23} – power lines, C_{24} – foil as packaging, C_{25} – aluminum dishes, D_{1} – substance^{1}_{ch}, D_{2} – substance^{2}_{ch}, D_{1} – physical bodies made of glass, D_{4} – free atoms, D_{5} – elements, D_{6} – compounds, D_{7} – physical properties of substances, D_{8} – example of aluminum applications, E_{1} – substances^{1}_{ch}, E_{2} – properties of substances, E_{3} – transformations of substances, F_1 – subject of chemistry.

Substances^{1}_{ch}, ^{2}_{ch}.

Having comprehended contents of the chemistry course paragraph, students can easily find a point where an interdisciplinary link is established, and independently insert the structure distributed by the teacher, like doing the puzzles. The following training targets can be achieved this way:
1) interdisciplinarity of physics and chemistry courses is ensured;
2) mobile learning devices help cover the interdisciplinary link issues within the frames of self-directed learning and thus save class hours;
3) teenagers’ undeniable desire to use gadgets for solving any issues whatsoever allows for the conclusion that the objective – building an interdisciplinary link in a structure using a gadget – is encouraged by the incentive.

Delivery in the form of a structure helps detect shortfalls of a paragraph content. For instance, the paragraph on chemistry illustrated by a graph in Fig. 1 introduces the notion of a substance in its second semantic state, namely, “Substance^{2}_{ch} as what consists of molecules, molecules consisting of atoms”. The paragraph lacks a reference to the forth state of a substance, previously studied in the physics course, as “what consists of particles with spaces between them”. Obviously, mentioning the
state would have facilitated explanation of the notion of a substance by the notions of an atom and a molecule as ultimate particles comprising a substance, through establishment of an interdisciplinary link to physics.

We, therefore, recommend to O.S. Gabrielyan, author of the textbook on chemistry, 8th grade, to eliminate the detected shortfall. A graph for the notion of a substance in this particular semantic state is given in Fig. 3. The graph contains description of five experiments, which allow for two conclusions (see \(E_4\) – experiment 1, \(E_5\) – experiment 2, \(E_6\) – experiment 3, \(E_7\) – experiment in Fig. 3).

![Figure 3](image)

The structure contains notions instead of graph nodes and is therefore a good teaching aid both for chemistry students and teachers. It reveals the need for establishing the interdisciplinary links and offers a choice of self-guided leaning tasks. In fact, the students can be asked to analyse contents of the paragraph and to find the shortfalls, namely, the lack of interdisciplinary links.

![Figure 2](image)

A colloquium, where every student is to present the interdisciplinary link he/she built using the archive of semantic structures of the notion semantic states, is another option. The number of tasks is

\begin{align*}
A_1 & \text{ – independence from creation, } A_2 \text{ – independence from human will, } B_1 \text{ – something existing, } B_2 \text{ features, } B_3 \text{ – chalk, } B_4 \text{ – hammer, } B_5 \text{ – strike, } B_6 \text{ – water, } B_7 \text{ – dye, } B_8 \text{ – mixing in a glass, } B_9 \text{ – metal ball, } B_{10} \text{ – ring, } B_{11} \text{ – passing a ball through a ring, } C_1 \text{ – conduct electric current, } C_2 \text{ – respond to light, } C_3 \text{ – conduct heat, } C_4 \text{ – matter, } C_5 \text{ – small pieces of chalk, } C_6 \text{ – strike, } C_7 \text{ – light-colored water, } C_8 \text{ – mixing in a glass of pure water, } C_9 \text{ – test tubes, } C_{10} \text{ – alcohol, } 40 \text{ mL, } C_{11} \text{ – water, } 40 \text{ mL, } C_{12} \text{ – mixing in a test tube, } C_{13} \text{ – ball passes through a hole, } C_{14} \text{ – heating a ball, } C_{15} \text{ – water, } C_{16} \text{ – flask with a glass tube in it, } C_{17} \text{ – heating, } D_1 \text{ – properties of substances, } D_2 \text{ – matter species, } D_3 \text{ – solids, } D_4 \text{ – liquids, } D_5 \text{ – gas, } D_6 \text{ – stretching, } D_7 \text{ – shrinking, } D_8 \text{ – fine pieces of chalk, } D_9 \text{ – strike, } D_{10} \text{ – light-colored water, } D_{11} \text{ – mixing in a glass of pure water, } D_{12} \text{ – mixture volume below 40 mL, } D_{13} \text{ – ball does not pass through a ring, } D_{14} \text{ – raising water level in a flask, } E_1 \text{ – substance } ^2 \text{ph, } E_2 \text{ – bodies, } E_3 \text{ – changing shape, } E_4 \text{ – experience 1, } E_5 \text{ – experience 2, } E_6 \text{ – experience 3, } E_7 \text{ – experience 4, } E_8 \text{ – experience 5, } F_1 \text{ – conclusion 1, } F_2 \text{ – conclusion 2, } G_1 \text{ – substance } ^3 \text{ph.}
\end{align*}

A colloquium, where every student is to present the interdisciplinary link he/she built using the archive of semantic structures of the notion semantic states, is another option. The number of tasks is
unlimited, provided that physics and chemistry teachers cooperate in distributing e-structures of the notion semantic states to their students. Indeed, tracing changes in semantics of physical and chemical terms in the process of learning the subjects is reasonable for fundamental concepts only.

We developed the method of isolating fundamental concepts from contents of a course using the intradisciplinary link graph model [10]. Using the model, an interdisciplinary content cluster is formed for a group of notions. By calculation of quantitative characteristics of a model for each notion, a hierarchy of the notions can be built up. This method was applied to the subject chemistry course. The notion of a substance established itself in the top position, which emphasizes its high level of significance in the course.

Thus, the two problems – interdisciplinarity and integrity of physics and chemistry courses – can be solved through engagement of mobile communication devices in the learning process, as exemplified in the article by the notion of a substance.

The research can be continued towards evaluation of entropy as a quantitative characteristic of information contained in the paragraph structure graph. Availability of the entropy value will help determine whether the course content needs to be optimized, and enable a comparison of information content of the same notions in physics and chemistry for the purpose to choose the one with less entropy.

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