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Graph Model of Intradisciplinary Connections In Example of General Physics Course

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Abstract. The model of an intradisciplinary connections was elaborated on the base of the theory of graphs. Every connection which appears in training content may be presented as oriented marked graphs. Each graph is a tree. In this paper we presented definition and model of intradisciplinary connections for example of physics course. The quantitative parameters of model are described in this paper. Quantitative method based on this model could be help to optimize a content of physics course. Furthermore using this model we can distinguish fundamental notions, laws and other elements of knowledge to separate hierarchical groups. This group is very important during the process of creating training course. Method of semantic structure attached to content of physics' lections and physical problems was described.

1. Introduction

The significance of modeling intradisciplinary connections in optimization of training course content is obvious. Optimizing the content of physics academic course is necessary due to several reasons including availability of different ways of describing natural phenomena in physics. The content of physics courses compiled by different authors can have different arrangement of sections and materials and hence, different interconnections. These connections depend on the level of "integrity" of intradisciplinary connections in the content of the course. If the degree of integrity (force) of every connection could be assessed, then the sum of forces would be equal to the integral characteristics of the course interconnectedness, i.e. its integrity. The course of physics with a higher integrity has a more interconnected content and is obviously more preferable for studying physics. Based on the course of general physics, the author of the article presents a graph model of an intradisciplinary connection whose quantitative features allows assessing the integrity of the course.

2. Graph Model of intradisciplinary connection

2.1. Definition of intradisciplinary connection

Many research works have been devoted to interdisciplinary connections; however, insufficient attention has been paid to intradisciplinary connections so far, a reason for that being a widespread opinion about the single nature of interdisciplinary and intradisciplinary connections. For example, V.A. Dalinger – "Internal connections between the elements of course structure can be established either within one subject or within different subjects, thus distinguishing between interdisciplinary and intradisciplinary connections" [1].

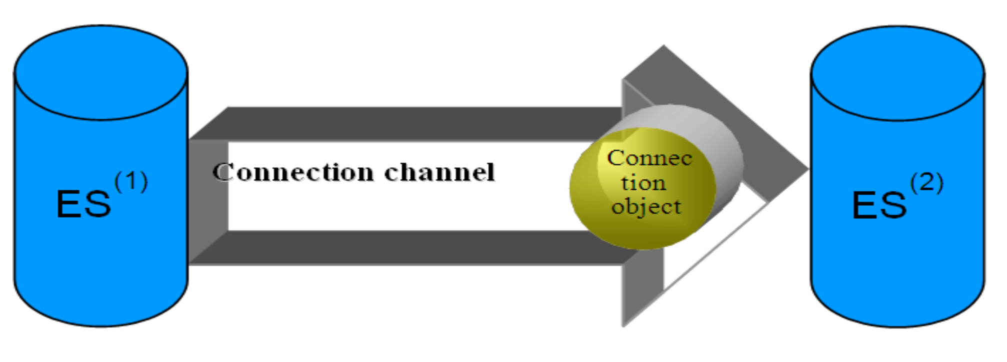

Figure 1. Illustration to intradisciplinary connection definition

Different interpretations of disciplinary connections suggested by other authors are similar in one area – pointing out that the nature of intra- and interdisciplinary connections is the same. In fact, connections appear in the moment of transmitting academic information. Therefore, in order to define the notion of intradisciplinary connections we will use the definition of interdisciplinary connections made in our previous research works [4, 6, 7, 8]. We define intradisciplinary connections as a construction of elements within a pedagogical system [3], which connects the structural elements of the educational intradisciplinary content and consists of (see fig.1) the following: object of connection – any element of knowledge, abilities and skills of the discipline – used at least in two elements of its structure; channel of connection – one or two elements of educational technologies coherent to the discipline where the connection is formed. The direction of intradisciplinary connections is defined by the sequence of studying the discipline and is set by the direction of transmitting academic information – from a structural element where the object initially appears to a structural element the connection is formed with. The definition of intradisciplinary connections determines that they all have the same direction.

2.2. Model

Definition of graph characteristics of intradisciplinary connections will be shown on the example of the traditional course of general physics (see, for example, [5]); we are going to use the approach defined in the works.

The structure of intradisciplinary content of the physics training course $\{ES^i\}$ can be presented as a set of twenty structural elements shown in table 1. The **objects of connection** are interpreted as elements of knowledge (principles, models, theories, laws and notions), skills and abilities used in the course of general physics.

Structuring the general physics course makes it possible to use the same elements of knowledge (principles, models, theories, laws and notions), the skills and abilities in studying various physical phenomena within an element of structure ES^i. We can unite the principles, models, theories, laws, notions and skills into the $\{EG_\mu^\nu\}$ sets or groups: $\{EG_\mu^1\}$ – group of notions; $\{EG_\mu^2\}$ – group of laws; $\{EG_\mu^3\}$ – group of theories; $\{EG_\mu^4\}$ – group of models; $\{EG_\mu^5\}$ – group of principles; $\{EG_\mu^6\}$ – group of skills and $\{EG_\mu^7\}$ – group of abilities. We use the following symbols: ν = 1,2,....,7 – index number of the group, μ = 1,2,...., μ_ν - index number of the element, μ_ν - number of elements in ν-group. For example, element $\{EG_8^2\}$ corresponds to the Lorentz force, and in the fragment of the group of laws shown in Table 1 it is $\mu_2 = 25$.

Intersection of $\{EG_\mu^\nu\}$ with a set of elements of the general physics structure $\{ES^{(i)}\}$ creates many nodes $\{J_i(EG_1^\nu), J_i(EG_2^\nu), \dots J_i(EG_\mu^\nu)\}$. This set falls into subsets of tagged nodes (nodes of Intradisciplinary connections) $\{J_i^*(EG_1^\nu), J_i^*(EG_2^\nu), \dots J_i^*(EG_\mu^\nu)\}$.; each of them gets tagged only if the element EG_μ^ν is used in the i-element of the $ES^{(i)}$ structure. In Table 1, these sets are tagged with "diamonds". For example, the subset of $\{J_i^*(EG_5^4)\}$ includes the nodes tagged by the fact of applying the law EG_8^2 ("Lorentz force"), in the following structural elements of general physics course: $ES^{(2)}$ ("Dynamics"), $ES^{(13)}$ («Magnetic field in the vacuum»), $ES^{(15)}$ («Quasi-stationary electromagnetic field»), $ES^{(18)}$ ("Electromagnetic waves in matter"), $ES^{(19)}$ ("Atomic physics"). Since students acquire intradisciplinary knowledge, skills and abilities in the process of studying, the intradisciplinary connections and corresponding tagged nodes are formed in the course of time. Therefore we will supply the subsets of nodes of intradisciplinary connections $\{J_i(EG_1^\nu), J_i(EG_2^\nu), \dots J_i(EG_\mu^\nu)\}$ with the subsets of nodes $\{J_{k\mu}^*(EG_\mu^\nu)\}$, tagged in case the element EG_μ^ν appears and is formed in the course of general physics for the first time. Here the k_μ index determines the index number of the structural element of general physics course where $\{EG_\mu^\nu\}$ appears first. For example, the Lorentz force $\{EG_8^2\}$ (see Table 1) first (time moment $\tau_{1\mu}$) is introduced in the second structural element -$ES^{(2)}$ («Dynamics»), whereas the well-grounded and most general concepts of the Lorentz force are formed much later (time moment $\tau_{0\mu}$)), in $ES^{(13)}$ («Stationary magnetic field in the vacuum»). This example illustrates time-distributed process of forming EG_μ^ν and hence, the intradisciplinary connection.

Thus, like interdisciplinary connections, the intradisciplinary connections realized through the EG_μ^ν object of connection can be described as orientable tagged graphs $\widetilde{G}_\iota(EG_\mu^\nu)$ (see Table 1). Each $\widetilde{G}_\iota(EG_\mu^\nu)$ graph of intradisciplinary connections is a tree, which starts from a tagged $J_{k\mu}^*(EG_\mu^\nu)$ node – the same for every intradisciplinary connection realized through EG_μ^ν. This node is tagged by the fact that the property of element EG_μ^ν is manifested sooner in it than in other tagged nodes. The graphs finish in the nodes of $\{J_i^*(EG_\mu^\nu)\}$ subset, which are tagged if EG_μ^ν is used in the ***i*** –element of $ES^{(i)}$ structure. Like in the graphs of interdisciplinary connections [4, 7], the $J_{k\mu}^*(EG_\mu^\nu\,)$ node is a root a single circle at the root of the tree of the abovementioned orientable tagged graph where there are no cycles. This peculiarity manifests itself in the fact that the leaf node of the graph of intradisciplinary connections $\widetilde{G}_\iota(EG_\mu^\nu)$ is adjacent to the leaf node of the subgraph $\tilde{G}_{i-1}(EG_\mu^\nu)$ (or overgraph $\tilde{G}_{i+1}(EG_\mu^\nu)$, if the latter exists. Therefore, the process of forming intradisciplinary connections can be interpreted as a transfer from the leaf node of one intradisciplinary connection of graph $\widetilde{G}_\iota(EG_\mu^\nu)$ to the leaf node of a different intradisciplinary connection, corresponding to the overgraph $\tilde{G}_{i+1}(EG_\mu^\nu)$. According to the sequence of studying the general physics course, this transfer geos from one structural element of general physics course to another, or through the nodes $J_k(EG_\mu^\nu)$, which reflects the dependency of the described process on the time. In this dynamic interpretation, the capacity of the intradisciplinary connection is a function of time or index number of the nod:

$$p_{im}^{(in)}(t, EG_\mu^\nu) = p_{im}^{(in)}(J_k(EG_\mu^\nu). \tag{1}$$

It is a quantitative feature of the connection considering the non-equivalence of connection channels, which appears due to the differences, for example, between the elements of educational technologies used in studying the same EG_μ^ν in different structural elements of general physics course.

This model of intradisciplinary connections allows introducing their quantitative features. If take that T_k – is a length of studying k – element of structure $ES^{(k)}$, then the time of creating the node $J_i^*(EG_\mu^\nu)$**,** calculated relative to the beginning of studying the general physics course is equal to:

$$t_i(J_\mu^\nu(EG_\mu^\nu)) = \sum_{i=0}^n T_k \tag{2}$$

Let's consider the homogenous model, constructed in the approximation of the time homogeneity of the course structure which says that the length of studying every element of structure $ES^{(i)}$ is the same and equals to the unit of *(T_i=1)*. Then, the time (2) of forming the node $J_i^*(EG_\mu^\nu)$ calculated relative to the beginning of studying the general physics course is equal to the index number of the element of structure $ES^{(i)}$. $t_i(J_\mu^*(EG_\mu^\nu)) = i$, and the length of connection is:

$$t_{k_\mu i}(EG_\mu^\nu) = i - k_\mu. \quad (3)$$

In the taken approximation of structural homogeneity of the course by time *(T_i =1)*, using (3), and capacity (1) of the connection $\left(p_{im}^{(ex)}\left(J_k(EG_\mu^\nu)\right) = 1\right)$, the expressions for effective length

$$L_{k_\mu i}^{(in)}(EG_\mu^\nu) = i - k_\mu \quad (4)$$

and effective continuous length have been simplified

$$\tilde{L}_{k_\mu i}^{(in)}(EG_\mu^\nu) = i - k_\mu - R_{k_\mu i}(EG_\mu^\nu), \quad (5)$$

where the length of gaps $R_{k_\mu i}(EG_\mu^\nu)$ equals to the number of non-tagged nodes between root $J_{k_\mu}^*(EG_\mu^\nu)$ and leaf $J_i^*(EG_\mu^\nu)$ nodes of the graph of intradisciplinary connections $\tilde{G}$ (EG_μ^ν). Relative maximal length of the intradisciplinary connection $L^{(in)}(EG_\mu^\nu)$ can be calculated by:

$$L^{(in)}(EG_\mu^\nu) = \frac{i_{max} - k_\mu}{N-1} \quad (6)$$

Existence of gaps, i.e. the structural elements of general physics course where EG_μ^ν is not used weakens the intradisciplinary connection. Therefore, on the base (4) and (5) the force of intradisciplinary connection is implemented $f_{k_\mu i}^{(in)} EG_\mu^\nu$:

$$f_{k_\mu i}^{(in)} EG_\mu^\nu = \frac{\tilde{L}_{k_\mu i}^{(in)}(EG_\mu^\nu)}{L_{k_\mu i}^{(in)}(EG_\mu^\nu)} \quad (7)$$

Then, integrity of the course can be interpreted as a sum of branching of the graphs of intradisciplinary connections within the total of knowledge elements for the group of knowledge elements

$$F_\nu^{(in)} = \sum_{\mu=1}^{\mu_\nu} \sum_i f_{k_\mu i}^{(in)} EG_\mu^\nu \quad (8)$$

or for all groups

$$F^{(in)} = \sum_\nu \sum_{\mu=1}^{\mu_\nu} \sum_i f_{k_\mu i}^{(in)} EG_\mu^\nu \quad (9)$$

3. Findings

Table 1 shows a fragment of intradisciplinary space of the general physics course. It is generated by intersection of multiple laws of physics with the set (N=20) of structural elements of general physics course. The cell is tagged with a diamond if a law is used in the material of a corresponding structural element of the course. The connection is established through every law between the structural element where this law is introduced and the one where it is applied. The table shows that the Lorentz force helps establish four connections. The existing chronological classification of intradisciplinary connections is well illustrated in this model. The objects of interdisciplinary connection EG_μ^ν can be used in the course of general physics during or after they have been formed, which corresponds to the current and subsequent intradisciplinary connections. For example, the intradisciplinary connections established through the object of connection EG_8^2 («Lorentz force»), are classified as follows. If we consider that the process of formation EG_8^2 ends in the 13th element of the structure of general physics course $ES^{(m_5=13)}$, then the intradisciplinary connection between $ES^{(2)}$ and $ES^{(13)}$ is current, and the connections between $ES^{(2)}$ и $ES^{(15)}$, $ES^{(2)}$ and $ES^{(18)}$, $ES^{(2)}$ and $ES^{(19)}$ – are subsequent. Calculation of the features of intradisciplinary connections by correlations (6) and (7) helped establishing the laws applied in this course of physics into a hierarchical sequence. First the laws are grouped by values of relative maximal length of connection $L^{(in)}(EG_\mu^\nu)$, use the formula (6), then they are ranked by the value of force of the intradisciplinary connection $f_{k_\mu i}^{(in)}(EG_\mu^\nu)$ – formula (7). Thus, the degree of significance of the element EG_μ^ν is defined by its position (determined by index μ) in the ranked set $\{EG_\mu^\nu\}$. Table 1 shows that the Newton's first law ranked 1st in the hierarchy; this law is a fundamental one by right. Among other fundamental laws there are the laws, which are used at least once in every section of the course. For example, in the list of fundamental laws, the Law of energy conservation ranks second, the

Law of conservation of momentum – fourth, and the Law of charge conservation – seventh, since, with the equal values of relative maximal length (equals to 0.89 for each law), the forces of intradisciplinary connections are different: 0.59, 0.24, and 0.12 correspondingly.

Table 1 Fragment of distributing the laws in the general physics course with the graphs of intradisciplinary connections established through the Lorentz force.

	Physics' Course Structure	***Mechanics***						***Molecular Physics and Thermodynamics***				***Electricity and Magnetism***					***Waves***			***Atomic and Nuclear***		Relative maximal length	Connection relative strength
												Stationary electric field		Stationary magnetic field				Electromagnetic Waves					
	Group of Laws	Kinematics	Dynamics	Conservation laws	Dynamics of rigid body	Vibration	Gravitation field	Thermodynamics	Statistic laws	Gases, Liquids	Solids	Vacuum	Matter	Vacuum	Matter	Electromagnetic Field	Elastic waves	Vacuum	Matter	Atom	Nuclear		
		an object for study																					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
1	1-st Newton Law		◆	◆	◆	◆	◆	◆	◆		◆	◆	◆	◆	◆	◆	◆	◆	◆	◆		0,89	0,79
2	Conservation of energy			◆	◆	◆	◆	◆	◆	◆	◆					◆	◆	◆	◆	◆	◆	0.89	0.59
	…																						
4	Conservation of impulse			◆	◆	◆		◆		◆								◆		◆	◆	0.89	0.24
	…																					…	…
7	Conservation of charge law			◆						◆		◆	◆	◆				◆		◆	◆	0.89	0.12
8	Lorentz force		◆											◆		◆			◆	◆			
			●●●●	→	→	→	→	→	→	→	→	→	→	►	→	►	→	→	►	►			
…	……																						
25	Ampere Law													◆									

4. Conclusions

Thus, we have elaborated the model of intradisciplinary connections, which interprets the connection as a tree-structured orientable graph. The model involves qualitative characteristics of intradisciplinary connections, which help optimize the structure of general physics course, conduct a comparative analysis of the course content, define the level of their integrity - formulas (8) and (9) and the hierarchical order, the calculation of which – formulas (6), (7) we noted above, of the notions, laws, models, theories and principles within the course, as well as define the fundamental core of the course. For example, the fundamental laws of impulse conservation, impulse momentum and Coulomb's law are studied not in every section in the described course. In comparison with the law of energy conservation, their significance is lower, since the traditional course of general physics does not contain the material, which involves using these laws; therefore, the connection is weakened. We can suggest, for example, supplying the section of Electromagnetism with the tasks of motion of charged particles in electric and magnetic fields that can be solved based on the laws of conservation of energy, impulse, and impulse momentum. The table shows the necessity of other revisions, which can strengthen the intradisciplinary connections and contribute to the formation of more comprehensive knowledge of general physics with the students.

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