Modeling the integrity of course learning using percolation through intra-disciplinary connections

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Abstract. This article deals with the problem of modeling the assessment of the level of integrity of the physics course content learned by students. The need for such modeling is due to the need to bring education courses to online format. The degree of learning integrity is proposed to be established by modeling the percolation of intra-disciplinary connections established in the course structure. The modeling uses a graph model of intra-disciplinary connections (Gnitetskaya T.) and the principles of percolation theory (P-theory). The article provides some practical solutions for the use of P-theory. An algorithm has been developed that allows forming the topics of the physics course into the structure examined for percolation.

1. Introduction
Preliminary formation of the content of an education course and establishment of its structural elements and intra-disciplinary connections between them is the key to the integrity of the material. In turn, an integral content of a course is one of the main criteria for successful learning of the material by students. At the same time, in like-named education courses different authors differently arrange a sequence of topics and contents, most commonly guided by intuitive ideas about the accessibility (understandability for students) of the proposed presentation logic. Which of the courses of different authors is the most integral? This question can be answered if we evaluate the integrity of these courses. A quantitative model of intra-disciplinary connections designed by T.N. Gnitetskaya (see [1]) allows for calculation of the course integrity. According to studies, a course with the contents characterized by the greatest integrity correlates with the best learning of the material [6]. Therefore, a model of disciplinary connections should be closely related with a model of the phenomenon of understanding, although we could not find any proposals for the development of the latter in the scientific literature. However, scientific articles have appeared where the authors determine behavior of various processes in education using the ideas of percolation theory (P-theory).

Thus, G. G. Korznikova proposes to use the P-theory for the design and analysis of various educational processes [3]. For example, selection of individual educational paths by students; designing the process of mastering professional competencies and exercising self-control over this process by the students; assessment of the level of mastering the competencies, which provides numerical reflection of the result content; assessment of the level of mastering the competencies based on the degree of learning the educational program, which in the author’s opinion allows for a conclusion about the quality of the program itself. At the same time, the author neglects the specific features of the percolation model in
the P-theory, where the connections are not definite. Sylvie Leleu-Merviel attempts to interpret the cognitive process based on the percolation theory. For this purpose, the author introduces a concept of interconnected fragments of knowledge in a knowledge cluster formed by consciousness [4]. It is noted that the connections between fragments established by consciousness can be diverse, but in order for percolation to occur the connections must be effective (p-efficiency). The efficiency criterion is compared with the critical value of the probability of connection formation, $p_c$. If the connections are formed with a probability $p$ satisfying the condition ($p \geq p_c$), then they are effective, if the condition ($p < p_c$) is met, then it is impossible to establish a connection between the fragments. However, the author does not investigate the factors affecting $p_c$ and does not establish the limits of its applicability, which suggests that this criterion will have its own fixed value for each individual person. Therefore, the range of this criterion is infinitely wide and generates reasonable doubts about the possibility of its assessment. Moreover, like in the above mentioned work of G. G. Korznikova, contrary to the requirements of P-theory concerning the inequality of connections, the percolation model is used for equal connections, and no reasoning is given that would make such interpretation of the model acceptable.

2. Formatting the title, authors and affiliations

Considerations for the application of the theory of percolation (P-theory) in the study of processes occurring on the earth surface are surprisingly simple, and the result is obvious without any mathematical calculations. For example, a grid with identical cells is superimposed on the map of the subject. Each grid cell cuts out a surface element. Establishing connections between the grid elements by a selected feature of the surface may with a certain probability cause the connection by this feature to “percolate” from one edge of the grid (surface boundary) to another. In other words, percolation occurs in this environment when a connection is made between elements belonging to the area boundary and those located at the opposite boundary. The minimum probability that ensures establishment of a connection — percolation — is called the percolation coefficient.

According to the described method, a model of water flow along the subject surface between its boundaries is built. According to S. Smirnov [5], the modeling is carried out in three stages. At the first stage, the entire surface is divided into hexagonal cells; at the second stage the cells are identified that bound the areas without signs of water, they are painted yellow while the remaining ones are white (see Fig. 1). There is no percolation probability between yellow and white cells. In turn, the probability of percolation between white hexagons is 100%. At the third stage, the white cells are painted over in blue depending on the presence of water connection with neighboring white cells (see Fig. 2).

Thus, a connection is established between the upper and lower boundaries of the area, which means the possibility of water flowing between the boundaries of the subject area along the most probable trajectory. The example considered above, which demonstrates the phenomenon of water flow through connections, prompted the authors of the article to the idea of modeling the percolation through interdisciplinary connections established in the structure of an educational course, in order to identify integrity of the education content learned by students.
3. Intra-disciplinary connections (graph model), percolation theory and optimization

The authors of this article propose to interpret the phenomenon of understanding as a result of percolation of the information contained in the educational course through intra-disciplinary connections. Thus, the integrity of the material due to intra-disciplinary connections is the key to understanding. Two tasks are formulated. The first one is to ensure integrity of the educational course material. This task is solved within the graph model of intra-disciplinary connections [1]. The second one is to establish the degree of integrity of students’ ideas about the course material after studying the course. We can consider the second task to be one of the subtasks of modeling the understanding based on the percolation through relationships. This article is devoted to the second task. In order to solve it, an educational course (for example, a course in general physics) divided into themes had to be represented in the form of a grid, where each theme fills a cell. Distribution of modules on this grid should not conflict with the principle of establishing an intra-disciplinary connections between structural elements through knowledge elements (for example, laws or concepts) [2]. The intra-disciplinary connection is interpreted as a structure made of the elements of the pedagogical system and consists of the connection object, which is any element of knowledge, skills and abilities (concept, law, model, theory, etc.) belonging to the discipline in question and used in at least two elements of its structure; the connection channel, which is one or more elements of the educational technology, adequate to the discipline wherein the connection is established. The direction of intra-disciplinary connection is determined by the sequence of studying the discipline and depends on the direction of educational information transfer – from the structure element, where the connection object appears for the first time to the structure element with which the connection is established. Intra-disciplinary information (connection object) is transmitted through the connection channel, one or more elements of pedagogical technology. Table 1 shows the intra-disciplinary space for a conditional educational course, where intra-disciplinary connections built in its structure through conditional concepts introduced and used in the material are shown based on the graph model of the intra-disciplinary connections. Such intra-disciplinary spaces built up for the General Physics Course were published in [7,8].

| Concept1 | Concept2 | Concept3 | Concept4 | Concept5 | Concept6 | Concept7 | Concept8 | Concept9 |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|
|          |          |          |          |          | ●        | ●        |          |          |
| ●        |          |          |●         |          |          | ●        |          |          |
|          | ●        |          |●         |          |          |          | ●        |          |
| ●        | ●        |          |●         |          |          |          |          | ●        |
| ●        | ●        |          |●         |          |          |          |          |          |
| ●        | ●        |          |●         |          |          |          |          |          |
| ●        | ●        |          |●         |          |          |          |          |          |
| ●        | ●        |          |●         |          |          |          |          |          |

Table 1. An example of the course structure.

Marks are put at the intersections of the horizontal lines of concepts and corresponding vertical lines of themes, which are the structural elements using the concepts as part of their content. For example, the concept 3 is included in the material of the second, fourth and fifth structural elements. A graph model of intra-disciplinary connections allows for calculation of the quantitative characteristics, including integrity. Integrity is considered as the sum of forces (an estimated performance of the model) of branchings of a set of knowledge elements included in the course content. If we change the sequence of themes, we can achieve maximum integrity. However, a different sequence of themes requires a different logic of presentation and changing the material contained in the themes. This is a rather time-consuming process. We use the percolation theory to determine the optimal sequence of themes. This article proposes to consider the conditional course shown in Table 1 as an example. The number of structural elements of the course is nine, which determines the choice of a square grid with nine cells. The intra-disciplinary connection between the themes is realized through elements of knowledge, for example, through concepts. The more connections there are between the two themes, the closer they can be in the grid. It should be noted that the graph model of intra-disciplinary connections involves building
the oriented graph branchings from the theme where the concept is introduced to all those where it is used. The orientation is disturbed in the grid, therefore, the maximum number of common connection objects is considered a sign of coherence within the grid for all the themes. This principle determines the stages of the algorithm for filling out the grid cells with the themes. At the first stage, theme 1 is placed in the upper left corner of the square grid (see Fig. 3).

At the second stage, themes are identified for the two cells bordering theme 1 cell by the maximum number of connection objects coinciding with those of theme 1. Table 1 shows that theme 1 has six intra-disciplinary connection objects in common with theme 5, and five in common with theme 2, therefore these two cells are filled out with themes 2 and 5 (see Fig. 4). At the third stage, a cell is filled, which borders with its angle with the angle of cell 1 and has full borders with themes 2 and 5. To do this, we should identify the themes that have the maximum coincidence of the number of connection objects with those of themes 2 and 5. There are two of them, namely, theme 4 and theme 7. The time sequence of the educational process coincides with the logic of its content. Accordingly, theme 4 is placed in the corner cell with theme 1 (see Fig. 5). The three-step algorithm is repeated for a cell with theme 4, which has a location similar to that of cell 1. Themes 7 and 9 go into the cells adjacent to theme 4, while theme 8 is placed in the corner cell (see Fig. 6). The remaining theme 6 falls into the last unoccupied cell. The grid filled with themes will look as shown in Fig. 3. It can be seen that it is not filled according to the rules of simple sequence. The same physics course published by different authors will have its own pattern for the theme distribution in the grid cells. It is important that in the framework of the proposed modeling, the connections between cells are not unambiguous, in compliance with the P-theory provisions.

4. Conclusions
Thus, the article provides a method for modeling the “connection grid”, adequate to the content of a particular physics course. The method is based on a graph model of intra-disciplinary connections. The “connection grid” of the course content is a combination of connection percolation paths from the beginning to the end of the course. That is, if the students questioned as to the content of the physics course have a decent knowledge of the material contained in theme 1, theme 2, theme 4 and theme 9, then their knowledge is bound with an inter-disciplinary connection. This connection permeates the entire course from one border of the “connection grid” of its content to the other one and described the integrity of the course.
Figure 7. Modeling of the integrity of the course learning by a student.

The developed method can be applied for solving the course optimization problem, provided that the percolation coefficient of the resulting grid is introduced, which will help establish the optimal sequence of themes for this course. Minimum value of the coefficient will be the optimization criterion. This suggests that the maximum percolation will correspond to the minimum percolation coefficient.

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