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Visualization of Knowledge in the Educational Process

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Abstract

The purpose of the study is to examine the theoretical and practical aspects of knowledge visualization in the educational process, to compare different models of knowledge representation, give an example of building an ontology to represent the subject area of knowledge visualization in the learning process, as well as an example of using Kohonen Maps to visualize student performance.

In the study, modeling methods were used to learn ontological and cluster models, methods of visualization and data systematization.

It is concluded that the visualization of knowledge is a complex, multicomponent concept that has a number of features in the context of the didactic principles of the educational process, the theory of the cognitive model of personality, the features of the perceptual properties of thinking, philosophical perception, the epistemological theory of knowledge and the theory of reflection of reality in the human mind.

Keywords: knowledge, knowledge visualization, modeling, educational process, ontology, Kohonen Maps.

1. Introduction

Knowledge visualization is, undoubtedly, one of the key directions in the development of modern knowledge engineering, and it is of great importance for improving the efficiency of the educational process.

In the work of V. Magalashvili and W. Bodrow we can find the following definition of knowledge visualization: “this is an area that borders knowledge management, psychology, graphic design, and pedagogy. The main goal of (knowledge) visualization is to improve the transfer of knowledge, to stimulate cognitive processes” [1, p.421]. It is also noted there that “knowledge visualization is a set of graphic elements and links between them used to transfer knowledge from an expert to a person or group of people, revealing the causes and purposes of these links in the context of the knowledge being transferred” [1, p. 422].

Martin J. Eppler and Remo A. Burkhard provide the following definition: "Knowledge visualization designates all graphic means that can be used to construct, assess, measure, convey or apply knowledge (i.e. complex insights, experiences, methods, etc.)" [2, p. 112].

V. Davydova in her work notes that visualization is not limited to illustrations: “Visualization means a cognitive technology for transforming semantic information into a visible picture” [3, p. 25].

V.D. Lobashev and I.V. Lobashev talk about the following manifestations of knowledge visualization as the most important direction for improving didactic tools:

– stimulates targeted development of cognitive processes;

– provides the process of knowledge transfer in the form of a processed, approved amount of information;

– ensures the integrative nature of knowledge areas from the point of view of the logic of interpenetration of initial concepts, postulates, regularities;

– tends to self-expansion, etc. [4].

The work of C. Vieira, P. Parsons and V. Byrd [5] shows that the visual perception of images has a rather complex perceptual-sensory nature and that visualization tools involve the cognitive and perceptual abilities of a person.

J. Thomas and K. Cook write about the need to develop a new set of visual paradigms that can solve the following tasks:

– facilitate the perception of constantly growing arrays of data of multiple types;
– provide a basis for the analysis of spatial and temporal data;
– promote understanding of uncertain and incomplete information;
– provide managed visualizations adapted to the user;
– support multiple levels of data and information abstraction;
– facilitate knowledge discovery through the synthesis of information based on data integration [6, p. 99].

Based on the foregoing, we can conclude that the visualization of knowledge is a complex, multicomponent concept that has a number of features in the context of the didactic principles of the educational process, the theory of the cognitive model of personality and the features of the perceptual property of thinking.

The purpose of this study is to consider the theoretical and practical aspects of knowledge visualization in the educational process, to study various models of knowledge representation, to give an example of building an ontology to represent the subject area of knowledge visualization in the learning process, as well as an example of using Kohonen Maps to visualize student performance.

2. Knowledge Representation Models

Knowledge representation models include methods for formalizing and structuring knowledge designed to reflect the characteristic features of knowledge, for example, their internal interpretability, coherence, structuredness, etc.

The following examples of knowledge visualization are considered in [2]:

– structured text and tables for systematization of knowledge;
– heuristic sketches (drawings that are used to help personal or group comprehension and communication process);
– conceptual diagrams, which are schematic representations of abstract that include using standard shapes (such as arrows, circles, pyramids, etc.);
– visual metaphors that transfer elements of understanding from a mastered subject to a new area;
– knowledge maps as schemes for applying knowledge;
– interactive visualizations and animations.

In [7], it is noted that examples of the main models and forms of knowledge representation include:

– production model describing knowledge in the form of a set of "If - then";
– a frame model based on Marvin Minsky's theory of frames, in the concept of which a frame consists of slots for placing objects that characterize the current situation;
– a semantic network representing a knowledge system of a certain subject area in the form of an integral graphic image of the network. The arcs of this network correspond to relations between objects, and the nodes correspond to the main concepts and objects of the subject area (one of the examples is ontologies as a way of formalizing the subject area using some graphical conceptual scheme);
– a logical model based on the system of calculation of logical functions (so-called predicates) of the first order.

When describing knowledge, the theory of fuzzy logic and fuzzy sets is also quite often used. As is known, the creation of the theory of fuzzy sets is an attempt to formalize the way of human reasoning, using the concept of a linguistic variable. At the same time, a linguistic variable is a variable that can take on the meanings of phrases from a natural language.

Certain languages and notations can also act as knowledge representation models. In this case, we will use the term “notation” as a certain system of symbols adopted in any field of knowledge.

In modern literature, the term “field of knowledge” is also widely used, which is a conditional and partially formalized description of the basic concepts and relationships between the concepts of the subject area, identified in the knowledge of an expert and presented in the form of a graph, diagram, table, etc.

By analyzing modern trends in knowledge visualization, T.A. Gavrilova, A.I. Alsufyev and E.Y. Grinberg cite the following classification criteria for visualization methods in knowledge management [8]:

- creation of visual images;
- codification;
- transfer;
- identification;
- application;
- change;
- marketing.

Consider the features of knowledge modeling in the educational process.

If we consider knowledge from the perspective of knowledge engineering, then knowledge is the patterns of the subject area (in the form of principles, relationships, laws, etc.) obtained as a result of practical activities and professional experience.

At the same time, knowledge can be considered both at the empirical level (for example, observations, facts) and at the theoretical level (laws, abstractions, generalizations).

The conceptual model of knowledge on the subject area can be built depending on its presentation level:

- at the object level: it is a set of objects of the subject area and a set of relations connecting objects (for example, in the form of a graph, infological model, etc.);
- at the functional level: reflects the model of reasoning and decision making (for example, in the form of a functional model);
- at the behavioral level: reflects the change in the subject area as a result of the occurrence of certain events (can be represented, for example, using a tabular model).

At the same time, the educational process has its own specifics that reflect the epistemological aspect of knowledge formation.

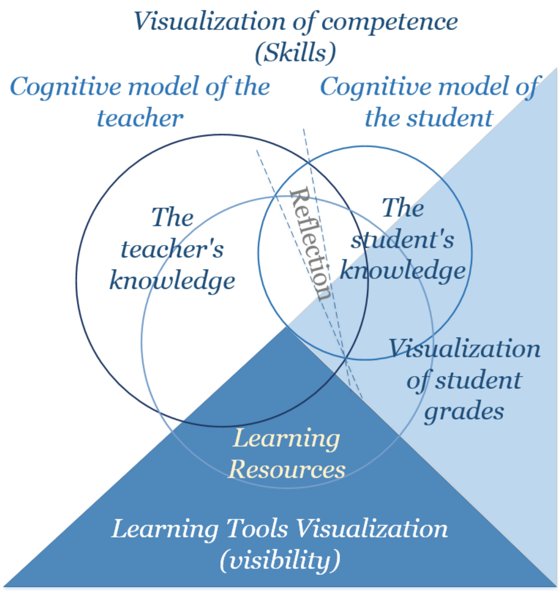

Fig. 1. Structure of the knowledge field of the educational process visualization

The epistemological nature of the transfer of knowledge lies in the fact that the knowledge and experience of the teacher are interpreted by the consciousness of the student, which already serves as the basis for building their own field of knowledge. The student's knowledge is a synthesized reflection of the scientific school of the teachers of their course, a reflection of the available educational resources, as well as the result of personal work and personal cognition (Fig. 1).

At the same time, it can also be noted that the educational process also includes the concept of metaknowledge as knowledge about the order and rules for applying knowledge (knowledge about knowledge).

Visualization of teaching aids in this case corresponds to the concept of the didactic principle of visualization of teaching. The works [6, 9] single out such principles of information visualization as Appropriateness Principle, Naturalness Principle, Matching Principle, etc. (Fig. 2).

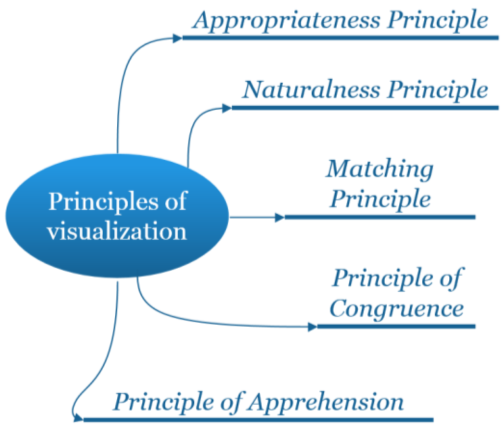

Fig. 2. Principles of visualization

Visual perception is based on the features of the perceptual property of thinking, that are reflecting events, objects, phenomena of the inner and outer world through the work of the visual senses. At the same time, the visualization competence consists of such elements as the analytical, visual-figurative, spatial-figurative, abstract-logical, etc. components (Fig. 3).

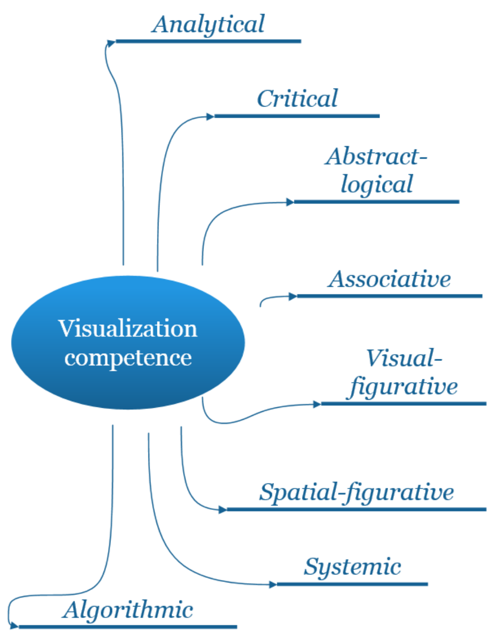

Fig. 3. Structure of visualization competence

Following the works [10, 11], we can say that the visualization of knowledge in the course of the educational process helps to solve the following didactic tasks:

– implement the principle of visibility in the educational process through the figurative representation of knowledge, their transfer, receipt and generalization on the basis of visual information;

– activate the educational and cognitive activity of students, taking into account their individual cognitive characteristics;

– develop analytical and critical thinking, improve the ability and skills of data analysis;

– form and develop visual-figurative and spatial-figurative thinking, visual perception;

– form the skills of systematization and structuring of information and study the methods of systematization and structuring of data, using visual-figurative and logical-symbolic models;

– develop abstract-logical and algorithmic thinking, logical skills, as well as associative thinking skills;

– improve visual literacy and culture of visualization, form professional competence in working with visual information in the field of future professional activity.

3. An example of developing an ontology to represent the subject area of visualization of knowledge in the educational process

In order to study the basic concepts of knowledge visualization in the educational process and their relationship, an example of an ontology model was developed that covers a number of aspects of the visualization of educational information from the point of view of the educational goals of the Department of Informatics and Information Technology.

For the software implementation of the ontology, the Protégé ontology editor was used, designed to build knowledge bases and based on the OWL web ontology language. This editor allows you to build a hierarchy of classes of the considered subject area (knowledge field) and has its own mechanism for defining classes and individuals, as well as setting their properties [12].

The main ontology classes are such concepts as:

– Disciplines: academic disciplines that form visualization skills (for example, Computer Science, Mathematics, Databases, Information Systems Design, Programming, Computer Graphics, Web Design, Intelligent Information Systems, Web Programming);

– Software: software used in the course of the educational process and corresponds to the concept of visualization competence formation (for example, analytical and statistical packages, spreadsheets, computer mathematics, logic circuit modeling packages, simulation systems, computer graphics systems, software interface design tools, computer animations, web design systems, computer presentations, engineering graphics systems, CAD systems, geographic information systems, landscape modeling systems, etc.);

– Knowledge_Models: basic knowledge representation models (production, frame, semantic, logical);

– Skills: basic visualization skills in terms of visualization competence components (analytical, visual-figurative, spatial-figurative, abstract-logical, etc.);

– Visualization: types of classes of visual objects (for example, drawings, illustrations, diagrams, models, presentations, flowcharts, program interface forms, animation, 3d graphics, design layouts, graphs, drawings, photographs, geoinformation maps, graphs, surfaces, diagrams , infographics, business graphics, OLAP cubes, semantic networks, ontologies, neural network graphs, clusters, cognitive maps, etc.).

Some classes also have their own subclasses, for example, in terms of notations, models are divided into subspecies:

– ER-models;

– IDEF models;

– ARIS models;
– BPMN models;
– UML models, etc.

Classes and subclasses include a subset of individuals that encompass a given domain object.

For example, the "Spreadsheets" software class includes such instances of the class as MS Excel, LibreOffice Calc, OpenOffice Calc, etc. The class of visual objects "Charts" includes such types of charts as histogram, bar, pie, ring, chiseled, combined, graph, surface, etc.

In figures 4 and 5, the ontographs of the constructed ontology for the subject area “Visualization of knowledge in the educational process” are presented. At the same time, fig. 4 shows the general structure of the ontology class hierarchy. Fig. 5 contains a fragment of the ontology of interclass relations, reflecting examples of the relationship between academic disciplines and classes of visual objects.

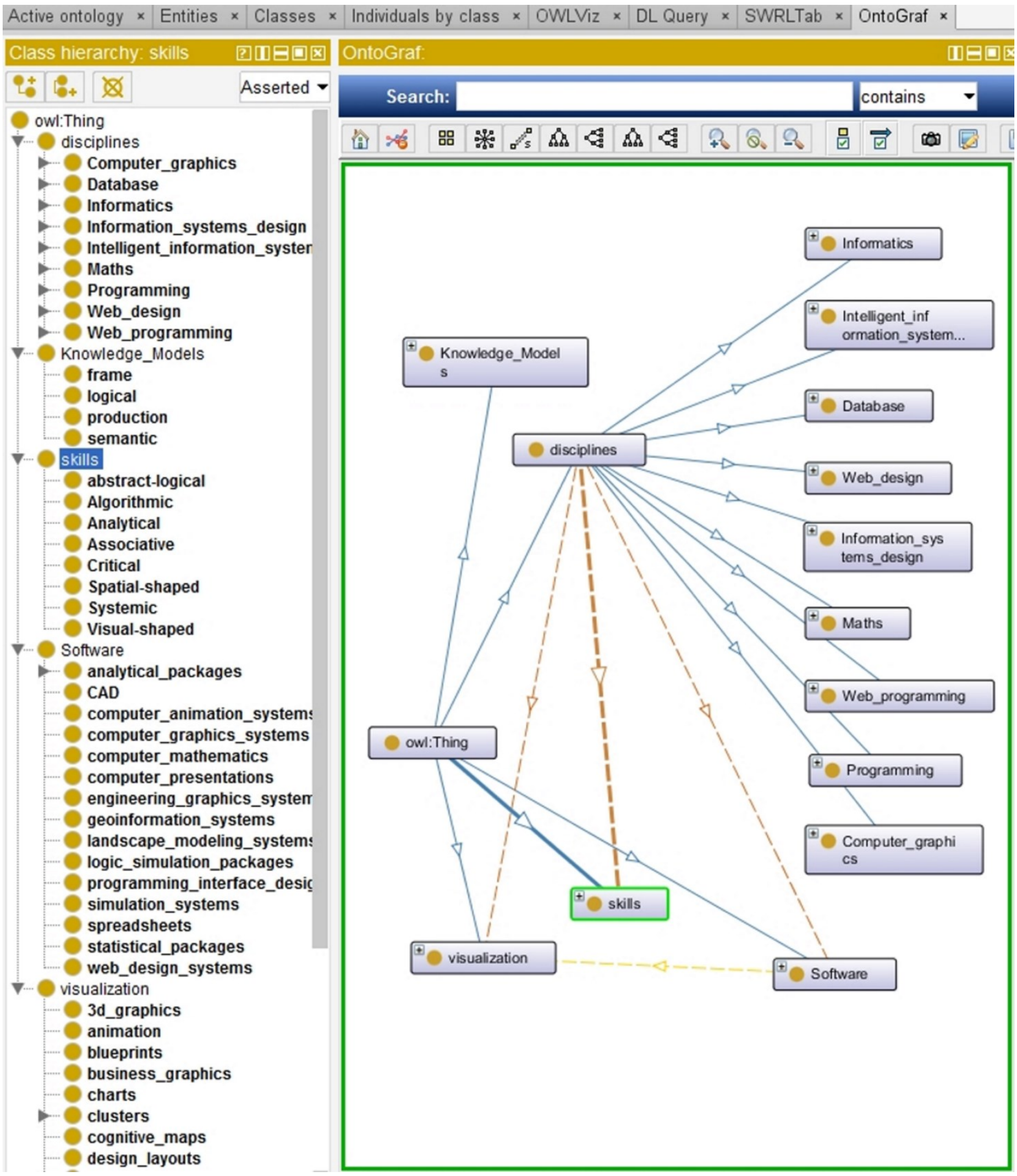

Fig. 4. The structure of the class hierarchy

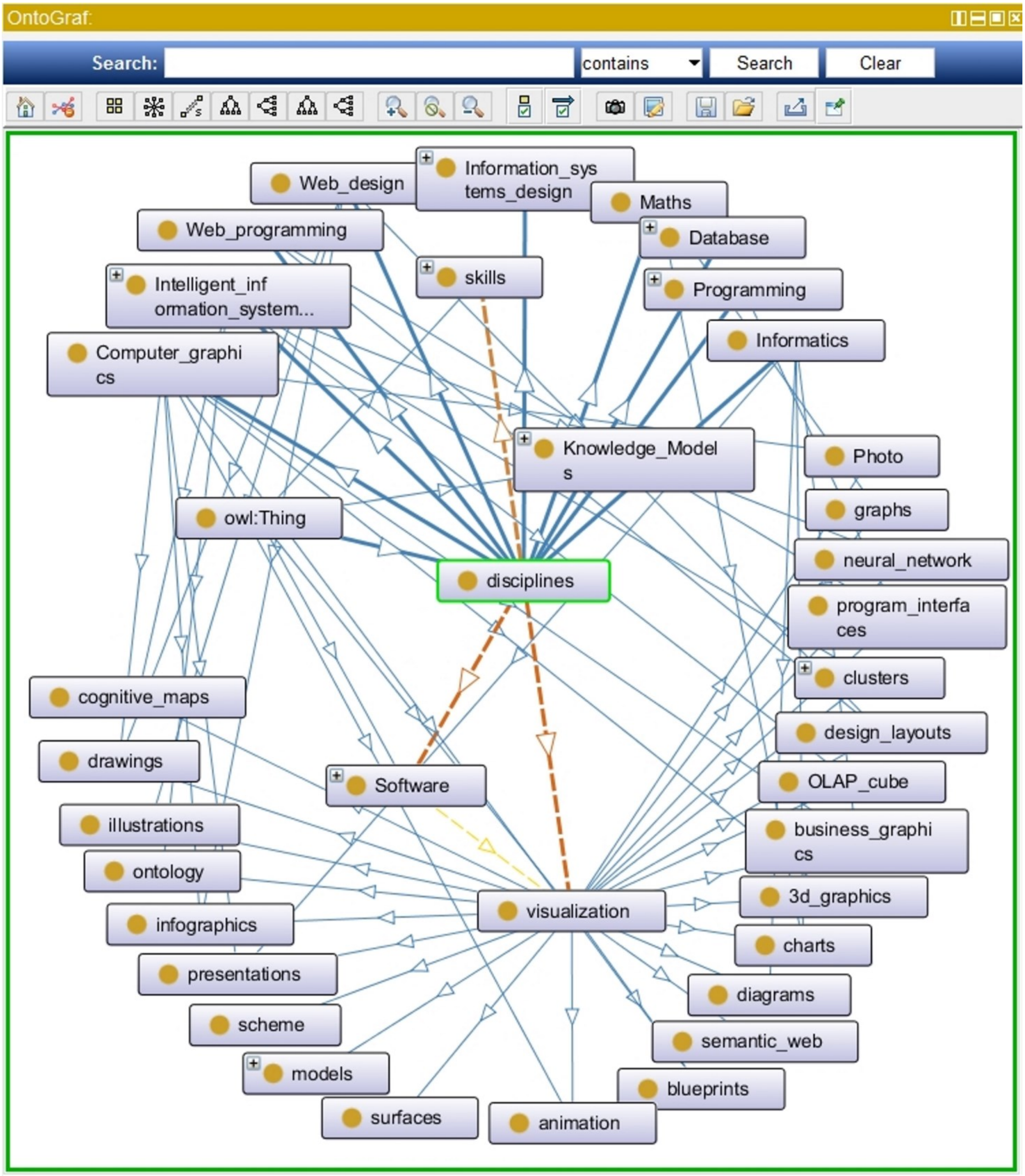

Fig. 5. Fragment of the ontology of relations between classes

4. An example of using Kohonen Maps to visualize student performance data

As an example of the visualization of the components of the educational process, let's consider using Kohonen Maps to visualize students' progress.

Kohonen maps act as one of the examples of Self-Organizing Map (SOM), based on the principles of a neural network with an unsupervised learning model. Maps consist of a number of projections, each of which corresponds to a certain analyzed indicator [13].

The choice of Kohonen Maps in the course of this study was due to their effectiveness in relation to the problems of clustering structured data arrays, accessibility in terms of software implementation and a high degree of visibility of the results obtained. The effectiveness of applying self-organizing maps to the problems of analyzing student performance in case of massive open online courses is shown, for example, in [14]. At the same time, it is said that this clustering algorithm makes it possible to facilitate the study of complex multidimensional data of the electronic gradebook, which can lead to a better understanding of the models of problem solving by students in the identified clusters. It also notes that SOM differs from other clustering algorithms in that it places similar data points (for example, students exhibiting the same learning behavior) close to each other in the X-Y plane, which makes it easy to visualize and explore complex data.

In our case, we considered the marks obtained by first-year students of the Business Informatics major at the Bashkir State Agrarian University in laboratory works (LW) in the electronic course of the "Information Systems" discipline in the e-learning management environment of the university (edu.bsau.ru).

The following types of work were evaluated as indicators:

- LW1 "Creating a single-table database";
- LW2 "Creating a multi-table database";
- LW3 "Requests with calculations and parameters";
- LW4 "Requests-Actions";
- LW5 "Creating and editing reports";
- LW6 "Development of graphic elements of forms";
- LW7 "Button Forms";
- LW8 "Creation of subordinate and related forms";
- LW9 "Macros";
- Ongoing assessment.

The number of students in the course is 63 people.

To carry out cluster analysis, the multivariate cluster analysis tool "Kohonen Maps" of the analytical program Deductor Studio [15] was used. This software package contains a large set of tools for analytics of multidimensional data, allowing, among other things, to implement cluster analysis tasks based on self-organizing maps using a visualizer in the form of a set of visual multi-color graphic objects-projections of maps. Working with this tool does not require the use of programming skills and includes the following main steps: preparation of a training sample; normalization of field values in order to bring them to the selected numerical scale; neural network training, including setting up training parameters from the proposed ready-made set of components; setting the data display visualizer [15, p. 141-145]. In this case, the numerical characteristic of the studied array of input data can change on each map projection within the color scale from dark blue (for the lowest indicators in the sample) to red (for the highest indicators) (Fig. 6).

In this case, the purpose of cluster analysis was to identify groups of students with similar indicators in terms of a comprehensive characteristic of the level of academic performance (to build different trajectories for further study of groups in an electronic course), as well as to identify tasks that caused the greatest difficulty for students (for further revision of teaching methods).

As we can see from figure 6, according to the results of cluster analysis, three clusters were built with numbers 0, 1, 2, corresponding to different levels of students' training.

The highest indicators are observed in cluster No. 2, located on the right side of each of the projections of the maps, it includes students with the highest academic performance (yellow and red). The students of this cluster have practically no unsatisfactory (dark blue) grades for current work, most of the work, with rare exceptions, was completed with “good” (yellow) and “excellent” (red) grades.

Average performance indicators were shown by students of cluster No. 1, located in the middle part of each of the projections. These students can be classified as "conditionally successful". In general, students coped with most of the course tasks, but have some unsatisfactory grades, which can be transformed by some correction of the further educational trajectory.

And the weakest indicators were demonstrated by students assigned to cluster No. 0 (located on the left side of all projections). Students in this cluster showed extremely low (dark blue) results in LW4, LW5, LW7, LW8, and also received low marks for other laboratory works. The progress of these students needs significant correction. It is necessary to conduct additional consultations for them, strengthen monitoring of their independent work, etc.

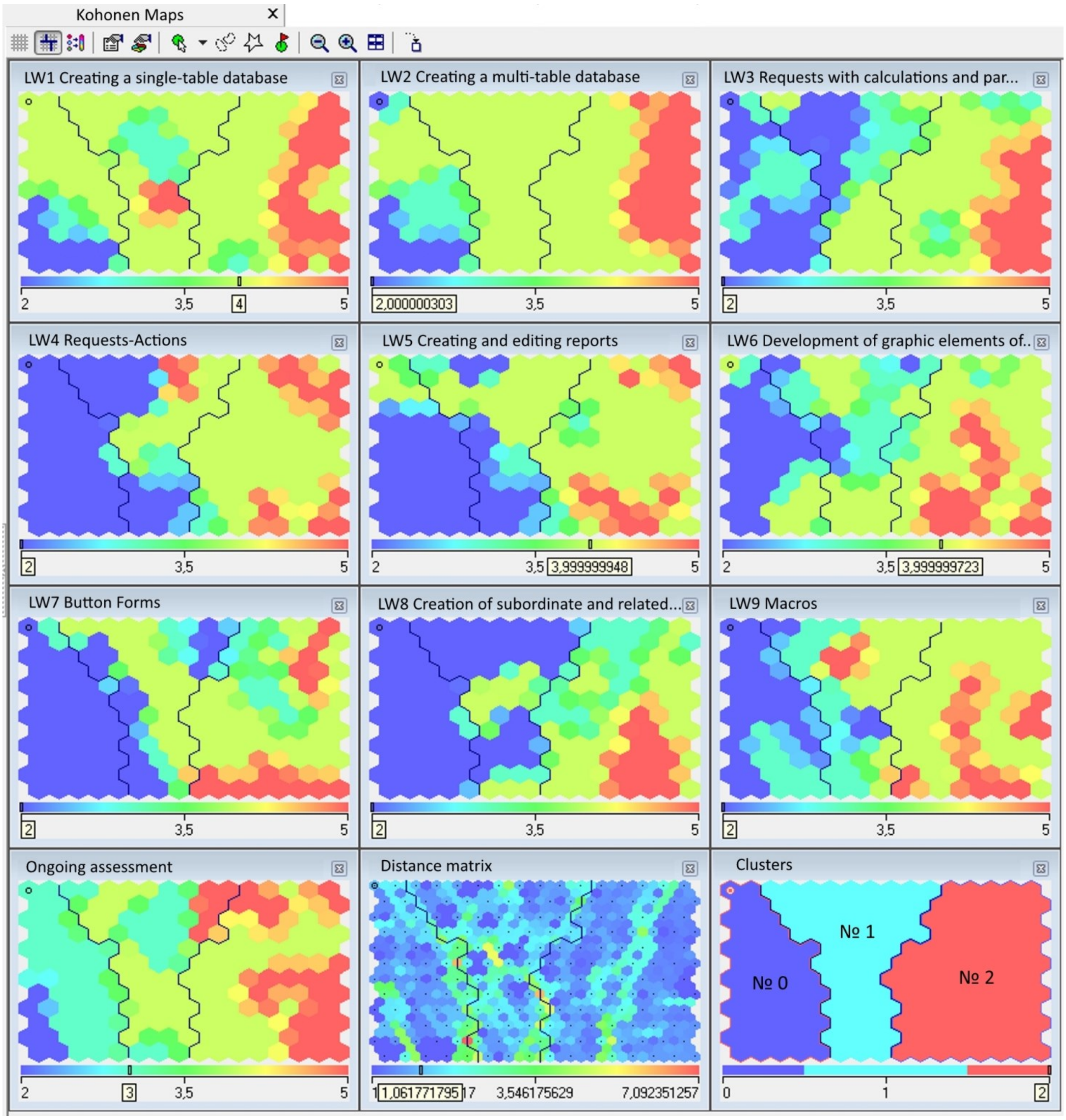

Fig. 6. An example of using the Kohonen Map to visualize student progress

A summary analysis of the "Profiles of clusters" and the names of students included in a particular cluster can be seen directly in the Deductor Studio system. In this case, cluster No. 2 included 30 students (47.6% of the total), cluster No. 1 is 15 students (23.8%), cluster No. 0 is 18 students (28.6%).

Conclusions about the complexity of the implementation of individual tasks of the course can be made. As you can see from Figure 6, LW8 “Creating subordinate and related forms” turned out to be the most difficult to study, this map projection has the largest amount of dark blue color, corresponding to the lowest student grades. Almost all students of cluster No. 0 and the majority of students of cluster No. 1 did not cope with this work, and some of the students of cluster No. 2 received “satisfactory” grades that are not typical for them. In addition, a large amount of blue color (unsatisfactory ratings) is also observed in the projections

LW4 "Requests-actions", LW7 "Button forms". It is necessary to pay special attention to these works, to revise the methodology of teaching these topics, to conduct additional consultations on them, to revise the guidelines for the implementation of these laboratory works, to increase the number of analyzed examples in them, to include additional detailed recommendations for completing tasks of individual options, etc.

In general, it can be concluded that Kohonen's Maps provide a visual representation of students' progress in the context of individual topics, and also visualize an integrated general idea of the degree of assimilation of educational material by students in the context of their clustering.

5. Conclusion

We can draw the following conclusions:

– visualization of knowledge is a complex, multicomponent concept that has a number of features in the context of the didactic principles of the educational process, the theory of the cognitive model of personality, the features of the perceptual property of thinking, philosophical perception, the epistemological theory of knowledge and the theory of reflection of reality in the human mind;

– visualization of knowledge in the course of the educational process helps to solve a number of didactic tasks related to the activation of the cognitive activity of students and the development of their figurative and analytical thinking;

– the formation of visualization skills in the course of learning activities is a complex task, depending on a large number of components; these skills are the basic factors for the formation of visualization competence;

– solving the problem of knowledge visualization requires the use of modern innovative technologies, covering end-to-end digital technologies, big data processing technologies, intellectual analysis of multidimensional data, etc.

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