Intelligent Learning and Testing Predictive System with Cognitive Component

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***Abstract*—In this paper an intelligent learning and testing predictive system with cognitive components used within the framework of blended learning paradigm is proposed. Current development trends in the field of effective learning technologies implementing student-oriented approach are identified. The developed system will enable the students not only to acquire the necessary competences within the subject area, but also to identify their successful educational approaches thus achieving significant results. Storage of knowledge is carried out by means of a semantic network, which allows establishing the correspondence between the material studied and acquired knowledge.**

***Index Terms*—intelligent learning and testing predictive system, cognitive graphic tools, blended learning, mixed diagnostic tests, semantic network, 2-simplex prism, e-learning course, student-oriented approach, learning results prediction.**

I. Introduction

All human activities are focused on the cognition process and the transformation of the world. Therefore, content that we, teachers, deliver to the student must be relevant, demanded and timely to solve emerging problems and to face challenges of the modern world. High-quality e-learning courses development based on intelligent learning and testing predictive systems with effective content delivery to the learner is a promising area of the modern teacher's activity [1]. Currently, the roles teacher plays in the learning process are as follows: 1) a teacher; 2) a content developer; 3) a motivator; 4) a moderator; 5) a business coach; 6) a scientist.

Broad field of students' cognitive activities may disorient them and lower their motivation. Therefore, a tool that offers teaching methods peculiar to a particular person facilitating to achieve the desired learning outcomes is required. The outcomes are described in a syllabus of a discipline and are formulated, taking into account the individual characteristics of a particular student.

Nowadays there is a demand in intelligent learning and testing systems development. They are in demand not only for learners, but also for teachers and specialists in various problem areas [2], [1]. Modern information technologies offer new opportunities for education and training. The teacher, using the paradigm of blended education and training with intelligent learning and testing systems support, provides face-to-face activities in the classroom and also develops the high quality content for the systems under study [1].

Blended learning paradigm within the framework of a modern university education encourages the development of effective distance learning methods for a large number of students with different activities [3]. In this regard, the development and use of online tests for learning and training is an urgent task for teachers and web programmers [4]. Cognitive graphic tools allow either to observe the solution immediately or to acquire a hint to its location [5]. That will enhance students' motivation and correct, if necessary, an individual learning trajectory.

The fundamentals of intelligent learning and testing predictive system with cognitive component are presented. The research results on the course "Selected chapters of electronics" using 2-simplex prism are also given herein.

II. Basic terms and definitions

We introduce a series of concepts and definitions for further use.

Learner is a person to be trained, for example, a student at the university.

Learning object is a question presented to a learner.

Learning pattern is a decision made by a learner.

Teacher is a person who conducts or supports learning process.

Diagnostic test is a set of features which differentiate any pairs of objects belonging to different patterns.

Unconditional diagnostic test is a test in which the order of the questions is not important.

Conditional diagnostic test is a test in which each further question in a chain of questions is dependent on the results obtained on the previous stages of testing.

Mixed diagnostic test is an optimal combination of unconditional and conditional diagnostic test components [6].

III. Principles of learning, testing and results evaluation

Using a variety of electronic resources and innovative teaching methods in the classroom within the framework of syllabus the specific discipline may serve as an illustrative example of blended learning model. Students and teachers are a part of the modern information society, which is characterized by an excess of information. That causes students' intellectual overloading. In this context, a key challenge is the development of educational content; methods of interaction between the teacher and the student and tests designed to evaluate the knowledge acquired by students. That requires significant time, cost and intellectual efforts [1], [3].

The growing interest in the development and the use of intelligent learning and testing systems stimulates the need for cognitive graphic tools that allow visualizing, analyzing and validation of the key performance indicators of the learning process. The indicators are as follows: the level of acquired knowledge, skills, competences and their combination. Moreover the system under study is able to predict the further effective education trajectory for each respondent [7].

Note that the learning cycle is represented via the 5 stages [8]:

1) Background knowledge activation on the course's topic.
2) Theoretical input: basic educational material introduction.
3) Understanding control, semantization and consolidation of theoretical material.
4) Simulation and case studies.
5) Acquired knowledge and skills application.

The proposed intelligent learning and testing predictive system allows to control the learning process at each stage of the learning cycle either by a teacher, or directly by the student.

The respondents assess their results within a particular module of the course and explore the prospects for further intellectual development on the basis of assignments performance and test results at each stage of learning cycle. The learning results prediction is implemented by the system under study in a certain direction of development. The next development directions are suggested to the students: 1) research, 2) practical, 3) teaching and 4) managing activities. Thus, the the system under study contributes to the development of the skills and aptitudes which are most expressed in particular student. That is detected by the tests results analysis and represented via cognitive graphic tool 2-simplex prism [3].

2-simplex prism is a triangular prism which has identical equilateral triangles (2-simplices) in its bases.

Thus, the intelligent system, focused on the learning, testing and prediction of learning outcomes is a means of training, validation of learning outcomes and constructing of individual learning trajectory. That, in turn, is a source of students' motivation. For teachers, such a system is a modern tool of analysis and efficacy improvement of teaching and learning processes. That significantly reduces the time and cost.

An alternative to students' knowledge data storage of the course is a semantic network which is described in the paper [9].

Motivation is an important issue of mastering a given discipline. The above approach creates further value attitudes of each student, facilitating further educational activities, according to learning trajectory designed.

An analogue approach in the field of technical disciplines is the method of dynamical programming, where the object is splitted into interconnected and interdependent parts. In the case under study each part is one more step towards the learning goals. Thus, with the current performance level of the student's knowledge and the trend of development, the student can identify forward-looking learning trajectory to develop their knowledge, skills and competencies in the desired direction, and follow it, providing the necessary control at each stage of the educational process.

It should be noted that the problem of information security is relevant in particular in the field of learning technology [10]. Data safety about the learning process and outcomes of each student is essential for reliable operation of the intelligent learning and testing predictive system at each stage of education. Information attack can damage the data, mix them. That leads to a distortion of the student's learning trajectory. This may entail psychological consequences both for students and teachers.

The system under study is aimed at arousing the students' endeavor to comprehend the discipline, to reach the learning goals both by students and teachers.

The value of knowledge acquired is determined by the student's ability to apply them in practice. That is an additional stimulus to the expansion of scientific and professional horizons.

The quality of the learning process is largely depends on students' goal setting. That needs to be written in detail in the syllabus of the discipline. The syllabus should be designed both for the student and for the teacher.

The student recognizes and applies sustainable successful learning methods on the basis of the learning results analysis. The predicted level of knowledge in the future depends on the current one which serves as a sort of initial conditions for each step of learning process. Within the framework of the course "Selected Chapters of Electronics" the following knowledge components were identified: 1) knowledge of theory, 2) problem solving skills and 3) laboratory work performance. The use of a 2-simplex prism to display the results on the above components allows visualizing and evaluating the individual learning trajectory.

The facets of the 2-simplex prism correspond to the evaluation of theoretical knowledge, skills to solve problems, and laboratory work performance skills. A point in the space of these components at a particular time instant, corresponds to the current evaluation of the above components combinations. That is illustrated via 2-simplex prism. In the process of learning the position of the point can vary depending on the students' values correction. Preferably, the position of the point should be within the area of tolerance.

However, the student could initiate some preferences in the learning process. For example, with poor theory knowledge, the student may solve the problems well and is very successful in experimental studies. In this case, the learning trajectory varies with orientation on practical activities. However, the system does not allow the student to get an evaluation based on 2-simplex prism, if he does not achieve acceptable results in the theoretical component of the course. Emphasizing the problems solving component leads to a positive impact on the other components. At the same time, given the coordinates of the level of knowledge at the previous learning step and development trend, the value of further level of knowledge, including all three components at a later stage could be predicted. Increasing the value of one component inevitably affects the other one.

As a result the students acquire the motivation to do more in their studies. Thus, the individual learning trajectory is constructed. Among the students' professional preferences the next ones could be outlined: 1) researcher, 2) specialist, 3) educator. This classification of learning trajectories can effectively orient the student to further professional activity.

Note the necessary components for intelligent learning and testing system with cognitive component construction.

To assess the student a bank of mixed diagnostic tests is needed. These tests are formed in such a way that students develop essential skills and abilities they need at the moment according to the individual learning trajectory, taking into account the current level of knowledge. If unconditional diagnostic test is performed successfully, the student is allowed to perform a conditional diagnostic test components which is evaluated using a mathematical apparatus, based on a combination of threshold and fuzzy logics [11].

Conditional diagnostic test is represented via interconnected and interdependent test questions that form the individual trajectory of passing the test. During testing, the system under study may return the student to any of the previous stages when the wrong answer to the current question is given. That reveals to undertaking the necessary additional training.

IV. Fundamentals of Construction of Intelligent Learning and Testing Predictive System with Cognitive Component

A block diagram of intelligent learning and testing predictive system with cognitive component is shown in Fig. 1.

A sequence of training (testing) of respondents in the developed system is as follows:

1) Respondent learns the discipline of interest or its module. Substantially, learning course in a related discipline may be submitted by the text with additional interactive and multimedia content. For the learning course storage the semantic knowledge representation model described in the paper [9] is used. This component is provided by a learning module.
2) On the basis of learning content the unconditional diagnostic test is constructed. In this case the sequence of test questions given to a student is not important. The learner answers the questions contained in the test of the unconditional component of the test. The present stage and the next two ones are provided using testing module.
3) The transition to the conditional diagnostic test component is performed. The previous answer determines the next test question of the interconnected and interdependent set of questions. Conditional diagnostic test component comprises: 1) questions of different level of complexity, related to the knowledge acquired using unconditional diagnostic test component; 2) questions evaluating the knowledge application to a particular task, combining already acquired competences.
4) During the test the database records all the steps that the respondent performs. This level of detailization is not necessary to calculate the respondent's assessment. Although it could be essentially useful for a researcher or teacher. On the basis of this sequence of steps, and the respondent's decisions the respondent's action card (RAC) is formed.
5) After completing all the tests the RAC is projected into a set of evaluation coefficients which determine how well the respondent copes with a variety of tasks on the basis of the following capabilities: 1) knowledge of theory, 2) problem solving skills and 3) laboratory work performance. At this stage the further trajectory of learning process is constructed. Pattern recognition module is responsible for this step.
6) After completion of the learning and testing the network of proven knowledge, RAC interpretation and calculated coefficients are shown to the respondent. The coefficients are visualized using 2-simplex prism. Comparison of the RAC and the semantic network of the course allows tracing between the material learned and the knowledge acquired, thus, indicating the gaps in knowledge. Further, if the respondent have module of the course which was not comprehended, or the test was not successfully passed, he can continue learning, returning to step 1. In this case, the student himself is involved in the decision-making process. He analyzes the results and seeing his perspectives, chooses his future scenario development. This step is attributed to results interpreting module.
7) In the case of successful tests completion throughout the course of study that the subject matter is considered successfully studied and the respondent has comprehended the learning course (with possible assumptions). In this case the overall learning process result can be represented as an average assessment through all the stages of learning and testing process, performed by the respondent.

V. Cognitive Visualization of Learning Outcomes and Their Prediction

The first and most complete application of the 2-simplex prism for the discipline "Power Electronics" is described in the publication [12]. In this paper, we use a number of fragments from the publication [12] required for further discussion. Example of learning trajectories using 2-simplex prism, based

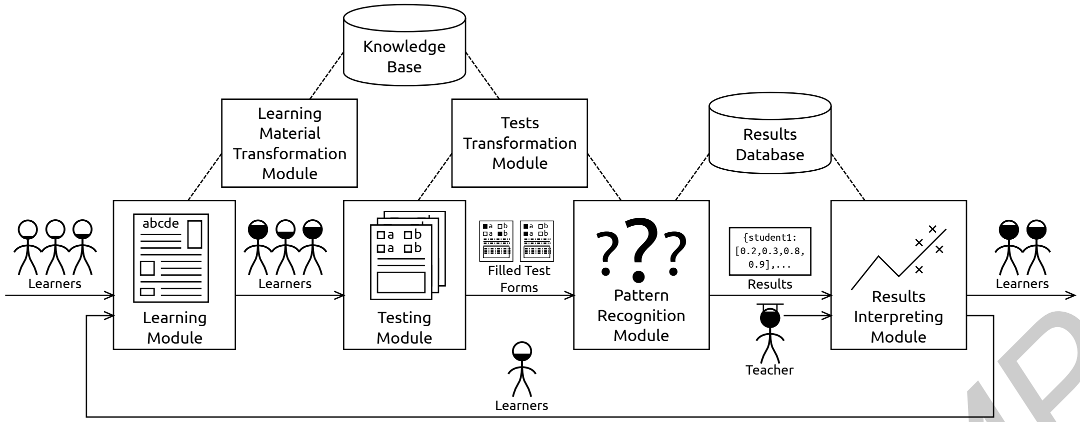


Figure 1. Block diagram of intelligent learning and testing predictive system with cognitive component

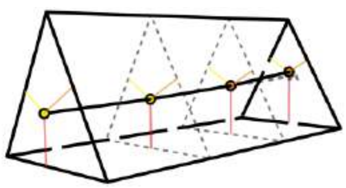


Figure 2. Using a 2-simplex prism to form a learning trajectory

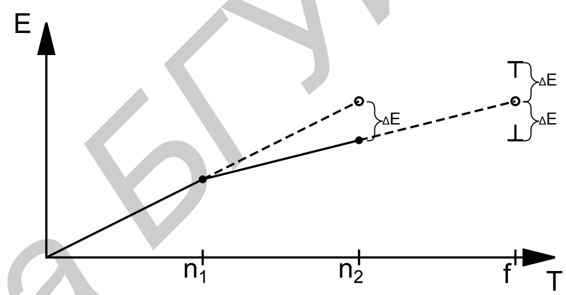


Figure 3. Example of confidence region prediction calculation.

on actual learning results, obtained with the use of mixed diagnostic tests is shown in Fig. 2.

The results of each of the four tests are shown in the form of points in a 2-simplices disposed on cross-sections of 2-simplex prism. Each face of the 2-simplex prism corresponds to one of the three patterns. For the majority of subjects taught in the universities, the following indicators are proposed to measure the knowledge level of the respondents: knowledge of theory (represented by red color in Fig. 2), problem solving skills (represented by yellow color), laboratory work performance (represented by green color). Each indicator is associated with corresponding pattern. The distance from the base of a 2-simplex prism to a specific 2-simplex corresponds to the time step from the start of learning to the particular testing (prediction). The height of the 2-simplex prism corresponds to total learning time plus the time interval after finishing the course. This time interval is used to represent the future results of the respondent.

A polyline within 2-simplex prism displays the evolution of the knowledge of the respondent. To assess the quality of the prediction for the last step the two lines used: solid and dashed. The solid line shows the progress of learning, revealed on the basis of the respondent's testing. The dashed line shows the prediction of the learning progress based on the previous performance of respondent. Confidence area of the prediction is presented by a triangle which consists of the dashed line segments.

Nowadays main aims are the following:cognitive graphic tools integration in the education process and estimation of an influence of learning process trajectory and its prediction visualization given for students on the speed of their learning. So, a quite simple prediction model for a learning process is used: 1) polynomial extrapolation is used; 2) learning axes are considered as absolutely orthogonal and independent and the values for each axis are predicted indepedently from other. The prediction model takes into account a history of testing results which a student has already obtained and gives a predicted result which a student should reach by the specified date. Polynomial power p is configurable and can be used for its influence estimation on a prediction quality. For a polynomial function the last $p+1$ results of already performed tests by a student for each axis are used. A system of linear equations is constructed based on the polynomial functions and is solved via Gauss method. It should be noticed that k is also configurable, so prediction can be performed for any future step, not only for the next one.

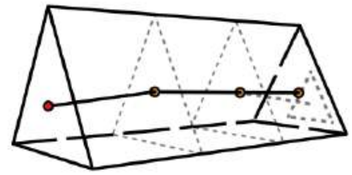
Confidence region prediction is calculated as delta between predicted and real result for the last performed test. Process of this calculation for one axis is shown in Figure 3.

Since the power of the polynomial is adjustable, it is possible to investigate the influence of this parameter on the quality of prediction. An example of the effect of the power of the polynomial on the quality of prediction is depicted in Fig. 4. By varying the power of the polynomial in the prediction process, it was found that for the majority of the respondents the best prediction is achieved by using a linear polynomial (the polynomial of the first power). This result allows to formulate the hypothesis, that on the basis of the learning progress second derivative it is impossible to reveal the progress of learning. For comprehensive confirmation of the hypothesis the study of prediction in a large number of tests is required. Other models of results prediction should be also applied to enhance the prediction quality.

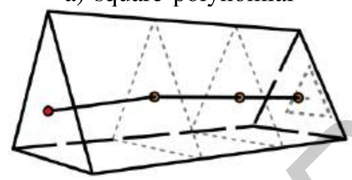
In most cases the chosen simple prediction model shows appropriate quality of prediction. That is why it will be used in the first version of the intelligent learning technology development. There are good grounds to believe that proposed approach allows to obtain the following results:

1) Illustrative representation for a student learning trajectory and trajectories comparison for different students.
2) Revealing and representation of a student learning speed.
3) Revealing of incorrect test results, e.g. revealing cheating on a test.
4) Predicting and modeling of a student learning process.
5) Increasing students' motivation to a high-perfomance learning by in-group competition increasing, which is accessible through providing both a comparison of student's results and other students results.

It should be noticed, that a major part of researches in this area are aimed at the development of vizualiation tools for teachers and administrators of universities and only minor part of them are aimed at the development for students, until they takes so much benefits for students as for teachers [13], [14]. Results of a few investigations [13], [14] shows advantages of the education model where visual representation for all students personal result is used, especially for e-learning technogies. The main reason why it works is an ability for each student to compare their results with an average and the best results among all students in their group. In paper [15] it is noticed that usage of social technologies allows to support a lot of metacognitive students actions, such as reflexion, planning, self-evaluation and increasing their motivation to learning. Special attention should be concentrated on cognitive graphic tools aimed at motivating the students competitive interests: their usage can increase the students interest to learning (the time spent on self-assessment tests) up to 20% [15].



a) square polynomial



b) linear polynomial

Figure 4. Influence of the polynomial degree on the prediction quality

VI. Specificity of Software Implementation of Cognitive Graphics Tools and Their Integration

The current software framework for a cognitive graphic tools visualization is written with a usage of JavaScript and WebGL [16]. It has a modular and extensible architecture which is presented in Figure 5. The library consists of three component groups: Input Processors, which make preprocessing data from the intelligent system outputs and serves as integration layer into the system; Scene Compositors, which are responsible for creating, configuring and placement of primitives; and Universal Primitive Library, which contains a lot of common components which are used during any scene creating. As this software version was developed based on web-technologies, it is very easy to integrate it into almost all intelligent systems especially web-based ones.

Integration with Moodle requires implementation of the following items:

1) Plugin for Moodle on PHP which append loading for our JS-library in front-end HTML-pages, extracts data from Moodle database and transfer them to front-end pages.
2) Input processor module on javascript which places HTML-element for the cognitive graphic tool and configures scene base on information acquired from the server-side PHP plugin.

It should be noticed, that all figures are rendered with a usage of visualization library which is currently at the early stage of active development. So they contain some small visualization problems, e.g. incorrect lines overlapping, and some necessary objects do not render at all, e.g. lettering for sides. Interactive demonstration for developed cognitive graphic tool, described in the present paper, is available by URL [17].

VII. Conclusion

Current state of research in e-learning area is discussed. The proposed intelligent learning and testing predictive system with cognitive component is designed to enhance the effectiveness of the learning process, to acquire the data for the analysis of the intellectual development of students in the educational process. The results obtained through the application of the system under study will effectively help to design the courses based on the blended learning paradigm. That could be performed by course content enhancement and its delivery improvement. Thus, the system could provide efficacy rise for both the students and the educators, motivating them to achieve their goals in efficient way. Having constant feedback, teachers perform real-rime monitoring of the learning process and solve the problems if necessary in a timely manner. Moreover, the individual characteristics of the students will be taken into account and learning preferences in accordance with students' values will be revealed.

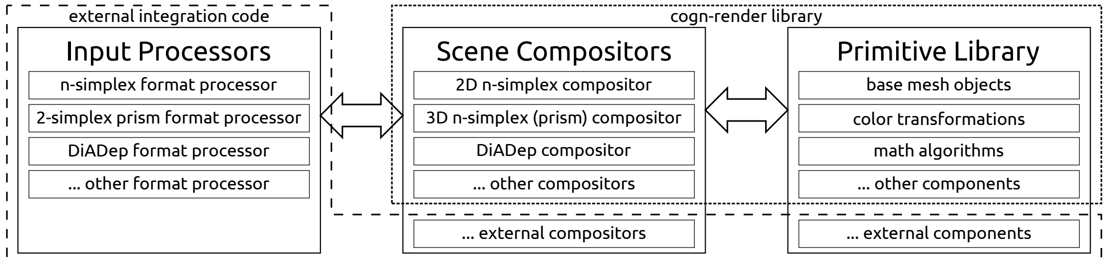


Figure 5. Architecture of library for congitive tools visualization.

The intelligent system allows identifying the student's value preferences, promoting career guidance and increasing personal effectiveness.

The system under study is offered for the courses: "Discrete Mathematics", "Information Security", "Automation and control", "Power Electronics" and others.

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ИНТЕЛЛЕКТУАЛЬНАЯ ОБУЧАЮЩЕ-ТЕСТИРУЮЩАЯ ПРОГНОЗИРУЮЩАЯ СИСТЕМА С КОГНИТИВНОЙ КОМПОНЕНТОЙ

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В статье предлагается интеллектуальная обучающе-тестирующая прогнозирующая система с когнитивными компонентами в рамках парадигмы смешанного образования и обучения. Рассматриваются современные тенденции развития в области эффективных технологий обучения, реализующих личностно-ориентированный подход. Интеллектуальная система позволит обучаемым не только приобрести необходимые компетенции в рамках проблемной области, но и определить успешные образовательные подходы для достижения высоких результатов. Хранение знаний обучаемых осуществляется с использованием семантической сети, которая позволяет установить соответствие между изученным материалом и полученными знаниями. Интеллектуальная система предлагается для организации процесса обучения в высших учебных заведениях различного профиля.