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Application of Learning and Testing Intelligent System with Cognitive Component Based on Mixed Diagnostics Tests

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Abstract

Relevance of computer based learning and testing of students is discussed. Learning and testing intelligent system (LTIS) is proposed for learning, testing, learning results and dynamics assessment. LTIS is aimed at professional and personal skills and abilities estimation, and also for designing learning trajectory of courses. A new assessment approach called mixed diagnostic tests (MDT) for LTIS construction is discussed. Analysis of the effective MDT and their implementation are proposed. The cognitive component based on 3-simplex and 2-simplex prism is suggested. MDT reduces both time and cost expenses for organization and control of the educational process. Since MDT may replace consultant function of teacher, the proposed approach is promising in the blended learning. The decision-making results are justified via cognitive component.

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Keywords: Learning and testing intelligent system; mix diagnostics test; cognitive component; blended learning; 3-simplex; 2-simplex prism.

1. Introduction

Nowadays development of learning and testing intelligent systems (LTIS) is relevant problem (Levin, et al., 2004; Brusilovsky, et al., 2006; Uskov & Uskov, 2010; Yankovskaya, 2011a; Yankovskaya & Semenov, 2011;

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Yankovskaya & Yevtushenko, 1997). Emerging information technologies provide a number of innovative and very promising technologies for teaching and learning. A significant group of the technologies are related to the distance, on-line education or to the education involving limited interaction between students and teachers. During the last decade, blended learning technologies have become ubiquitous (Singera & Stoicescu, 2011; Graham, 2006). Such technologies affect both the educational practice and the principle approaches to the distance education by improving collaboration which is a very important component of education. At the same time, the problem of assessment and improving efficiency of the educational process becomes relevant even more than in a conventional class, due to absence of the teacher in such a class. The concept of blended learning, which is a learning combining both education and training, was introduced in (Bliuc, et al., 2007). In general, the blended learning corresponds to an integrated learning environment, which combines e-learning with traditional classroom teaching (Graham, 2006). One of the main problems of high school is to develop mechanisms for effective training a large number of students by a wide diversity of tasks (Singera & Stoicescu, 2011).

The simplest example of the blended learning is using diverse resources and methods within the structured and targeted syllabus. Despite of the variety of information technologies (including methods of artificial intelligence), methods for diagnostics of the gained knowledge in the teacher-student interaction are not developed enough. The development of such methods is highly time-consuming and requires considerable efforts (Brusilovsky, et al, 2006; Uskov & Uskov, 2010). Students of different abilities have diverse preferences in learning and achieving goals of lessons. Ausburn (2004) used a questionnaire aimed to study students' abilities, such as the initial level of their knowledge, skills, and experience. Orientation on student's particular interests and capacities should make the learning process more effective. Any student (bachelor, master and specialist) should rely on experience and skills obtained at a higher school to find the proper solution of educational and industrial tasks. Moreover, the student should understand very clearly, why and how he/she will use the obtained knowledge, professional and personal skills, and abilities to reach his/her goals. Bliuc et al. (2007) identify four different ways to define the blended learning. The blended learning can be considered as: a) combining modes of web-based technology; b) combining of various pedagogical approaches; c) combination of instructional technologies with a face-to-face instructor-led training; or d) combination of teaching with practical work.

In our paper, we propose a new approach for learning and testing based on mixed diagnostics tests (MDT) LTIS with cognitive component. The approach is based on so-called MDT introduced by A. Yankovskaya in 1996 for intelligent systems construction and further developed for LTIS construction. MDT being one of the most adequate and useful tools is a compromise between unconditional and conditional components which expediently to use in blended education and training. The most effective ways of learning and testing results assessment in LTIS based on MDT is cognitive graphic tools (Yankovskaya, et al., 2014a; Yankovskaya, et al., 2014b). The cognitive graphic tools are used in different intelligent systems for information data and knowledge structures analyzing, for revealing regularities of different kinds and decision-making and its justification. They are widely used in LTIS for teaching and learning activities optimization, for visualization and learning process results forecasting, etc. But the development of these tools for each problem area is very time-consuming and expensive. In the cognitive tools which are invariant to different problem areas were developed (Yankovskaya, 1997). Application of these tools is relevant both for the objects' parameters analysis and for decisions justification as well as for dynamic processes analysis. Visualization simplifies the information analysis and allows decision-making in effective way.

Present paper continues the research on creation of based on MDT LTIS with cognitive component invariant to the problem area. Mathematic basis of an object under study representation in n-simplex is briefly described and basis of representation of a process under study in 2-simplex prism is given. Examples of 2-simplex prism application in developed and developing LTIS are presented. Further research directions are proposed.

2. Problem background

The modern society involves dynamic, frequently unpredictable changes, which call for students and graduates to be able to solve different educational and professional tasks (Singera & Stoicescu, 2011). It should be noted that blended education and training calls for an extension of range of skills, experience and knowledge (competences) of both teachers and students. Students of different abilities have diverse preferences in process of learning and reaching their goals. In her study, Ausburn (2004) used a questionnaire aimed to assess university students' abilities such as initial level of their knowledge, skills, and experience. Orientation on a student's particular interests and capabilities should make the learning process more effective and economic. The blended learning is known as the learning with a high level of redundancy of possible learning trajectories. An important example of the blended learning with high level of redundancy is learning subjects owing to multiple representations (Levin, et al., 2004). In (Yankovskaya, et al., 2013) the MDT is used in order to design specific trajectories of students' educational processes. Blended learning and testing using MDT is alternative attempt to the traditional educational approach, for example by providing flexible opportunity for the design trajectory of education and assessment. Implementation of the MDT in LTIS was presented in (Yankovskaya & Semenov, 2013). Using MDT allows to overcome weak motivation of students and to organize the purposeful approach to improving the quality of studied material during a semester. Bliuc et al. (2007) identifies four different ways in which blended learning can be defined. Blended learning can be seen as: a mix of modes of web-based technology, or a mix of various pedagogical approaches, or a combination of any form instructional technology with face-to-face instructor led training, or a combination of instructional technology with actual job tasks (in order to create an effective mix of learning and working). In difference from the research presented in the publications (Yankovskaya, 2011a; Yankovskaya & Yevtushenko, 1997; Yankovskaya & Semenov, 2011) we suggest using MDT to design of the educational process trajectory. Presence of variety in the educational process (possibility to choose of trajectory) is highly appreciated by students in blended education and training.

Test is the set of grouped characteristic features (and/or the characteristic features). Unconditional component test is characterized by the simultaneous presentation of its constituent features of the object (student, course) during the decision making. Conditional component test is characterized by the sequential presentation of features, depending on the value of the previous features. We suggest that a test is diagnostic test, if as a result of its passing students access the correct result and detecting test if there is only available outcome. The students receive the test result.

Unfortunately, presently available testing methods motivate students very insufficiently. The main advantage of MDT approach is in providing flexibility in designing of learning trajectories. According to our hypothesis, more flexible learning trajectories allow increasing motivation of students and improving quality of the learning process.

For effective implementation of MDT approach we should solve the following tasks: a) offering students the instrument for designing their own learning trajectories, b) providing interaction of a teacher and a student, and c) increasing accessibility to information. We expect that a process of learning and training will be effective and economic as a result of this approach based on MDT.

Cognitive component is one of the most essential part of LTIS. An important contribution to the development of the cognitive science was made by (Axelrod, 1976; Pospelov, 1992; Zenkin, 1991). First steps in the development of the cognitive graphics tools were made, and thereby a new research direction was formed by Zenkin (1991). Cognitive tools are very effective for the interpretation of analyzed data and knowledge, decision-making and its justifications for users specialized in different problem areas but are not specialists in algorithms of data analysis and knowledge, inference in intelligent systems. One of the cognitive tools is based on the n-simplex (Yankovskaya, 1991). Undoubtful advantages of the cognitive tools based on n-simplex are invariability to the problem areas.

Basic problems can be formulated as follows. An educational course is divided into some sections; each of those consists of didactic units. It is required to construct a MDT for each course and each its section and to decision-making on the base of MDT and cognitive tools via LTIS.

3. Construction of mixed diagnostic tests

Different models can be used for training, testing, and controlling student knowledge, such as automatic or graph (network and treelike) (Yankovskaya & Yevtushenko, 1997). In this paper, the results of decision making were evaluated with due regard for the optimal path of decision making. An expert in a given domain of knowledge must partition the set of sections of each study course into two subsets for the list of study courses to be analyzed. The first subset includes the unconditional component of the MDT, i.e., the sections (grouped characteristic features) and didactic units (characteristic features) that are presented to students (respondents) in a random sequence.

Let us present the possible sequences of test tasks in the form of a search tree. The root node of the search tree is associated with the unconditional component of the mixed test. The presentation of a grouped characteristic feature (CHF), the same as the CHF from the second subset (the conditional component of the test), depends on what previous feature was presented on an appropriate level of the search tree. Each branch of the tree is a permissible sequence of actions to select the section (didactic unit) that leads to a leaf. Each leaf is associated with a result of test passage. It should be noted that the order of features at the same level of the search tree does not matter. The passing of the search tree branches is performed from left to right.

4. Learning trajectory design of course using MDT

Designing learning trajectory of course using MDT will be illustrated on the example of MDT construction for the university course "Information Technology" for specialization "Industrial and Civil Construction". The main sections of the course are as follows: 1) the concept of information; 2) a general description of the data collection, transmission, processing and accumulation of information; 3) hardware and software implementation of information processes; 4) decision models of the functional and computational tasks; 5) algorithms and programming; 6) high level programming language; 7) database; 8) the software and programming technology; 9) computer graphics; 10) computer practice. Each grouped CHF contains a different number (from 4 to 8) of didactic units (CHF).

An unconditional component of MDT includes grouped CHF of sections 1–3. Note that grouped CHF (Section 3) should be parted into two: "3.1. The technical tools to implement information processes" and "3.2. Software implementation of information processes". A conditional component of MDT includes grouped CHF of 3.2, 4–9.

An example of search tree of MDT is given in Fig. 1. The numbers of the course sections are written in tree nodes (represented by rectangles). Objects assigned with the unconditional component of MDT (sections 1, 2 and 3.1) are listed in the root node of the tree. Transition to knowledge control on course sections which relate to the conditional component of MDT is provided if the student has successfully completed the task on the unconditional component of the diagnostic test if he scored at least 50 percent of correct answers. Branches of tree are marked by letters a, b, and c on arcs coming out of the root node (Fig. 1).

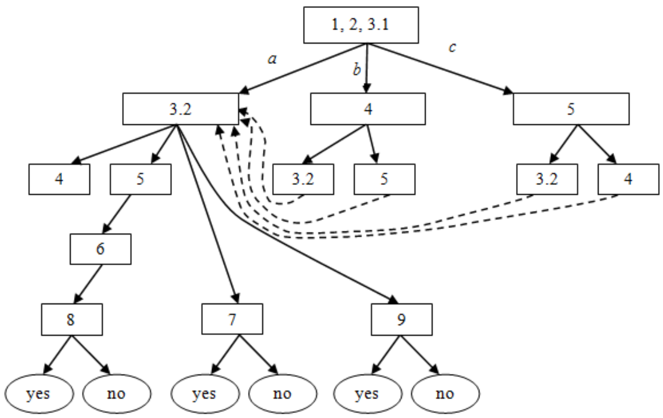

Fig. 1. Example of the mixed diagnostic tests (MDT) search tree.

During the construction of MDT a possibility to skip of a section is excluded and students are invited to explore the section which the study of sequent next sections depends on. Full sequence of branches tree search for the section 3.2 is shown in Fig. 1. Thereafter the student may proceed to carry out assignments from section 4 or 5. Similarly on tasks for sections 4 and 5 he can proceed to implement the tasks of the sections 3.2 and 5 or 3.2 and 4 respectively. One of the possible variants of the conditional component of the test is the following admissible sequence: 3.2, 4, 5, 6, 8, 7, 9. Applied part of course from section 10 may be indirectly presented in each of the sections 1–9 as practical tasks. The tree leaves are shown as ovals. The test results were compared to the tree leaves. The tree edges with dashed arrows indicate the possible transitions of passing a conditional component of MDT.

We have sequence of different courses and sections (topics) for each course. The number of courses during a semester is defined by an expert (or group of teachers). The complexity of courses based on credits of each courses. A student can choose a form of education and training from the different approaches and resources. Decision-making about a student's level of knowledge, professional and personal skills and abilities is carried out using elements of fuzzy logic and threshold function (Yankovskaya & Semenov, 2012).

5. Flowchart of the algorithm for the construction of a mixed diagnostic test

We will present an informal description of the algorithm and a flowchart (Fig. 2) for MDT construction.

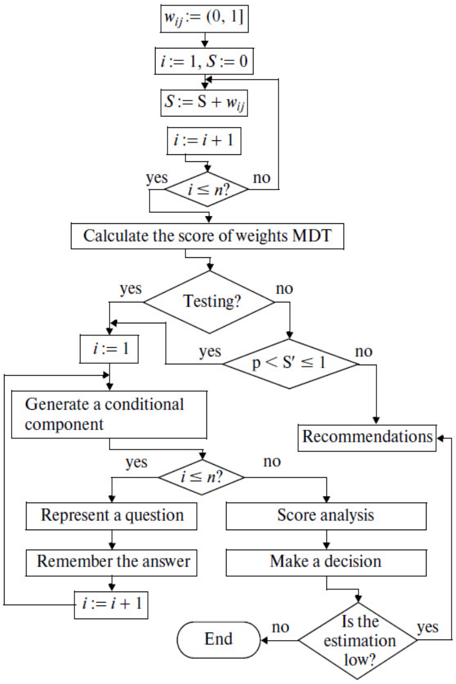

Fig. 2. Flowchart of the algorithm for MDT construction.

It is necessary to indicate the conditions for MDT operation (learning or testing). For each course or each didactic unit MDT formation algorithm close to one given in (Yankovskaya & Semenov, 2011) should be performed.

1. Assign to a weight w_{ij} ($1 \leq i \leq n$, $2 \leq j \leq k$ for an unconditional component and $1 \leq i \leq m$, $2 \leq j \leq k$ for a conditional one) to each question (each component included in MDT) within an interval from 0 to 1.

2. Generate the unconditional component of the next MDT.

3. Find the weight S of the conditional component of MDT which equals the sum of the weights of all components w_{ij} of the unconditional component of MDT.

4. Calculate the student's score S' by the components of the unconditional component of MDT. Find $p = S'/m$. calculate p_r by each conditional component and divide the obtained result by the number of questions of each MDT component (conditional and unconditional).

5. If p is $p_r \geq 0$ then go to point 8.

6. In training, if a student did not score the required weights of answers then go to point 7. In the case of testing, evaluate the result as poor and recommend that he should repeat the training. Go to point 15.

7. Give advice to the student on the passage result of the MDT unconditional component. Go to point 2.

8. Generate the first component of MDT conditional component in question.

9. Represent the next component of MDT conditional component to the student.

10. Increase the score of the weights of a student's answers by the weight of the received answer on the next component of the MDT conditional component in question.

11. Verify whether all the components of the conditional ones of MDT have been presented to the student. If no, then generate the next component of the conditional one of MDT and go to point 9. If not all of the conditional components are analyzed, go to point 8. Analyze the score of a student's answers as the result of passage of the MDT. Evaluate the student, i.e., make a decision as to whether he passed MDT based on the scored answer weights.

6. Cognitive component in LTIS

The cognitive component in LTIS based on n-simplex family according to the Yankovskaya's theorem (Yankovskaya, 1991) and 2-simplex prism is purposed to visualize parameters outlined in the theorem.

Theorem. Suppose $a_1, a_2, ..., a_{n+1}$ is a set of simultaneously non-zero numbers where n is the dimension of a right simplex. Then, there is one and only one such point that $h_1 : h_2 : ... : h_{n+1} = a_1 : a_2 : ... : a_{n+1}$, where $h_i (i \in 1,2,...,n+1)$ is the distance from this point to *i*-th side.

Coefficient $h_i (i \in 1,2,...,n+1)$ represents the degree of conditional proximity of the object under study to *i*-th pattern. The advantage of this fact is the n-simplex possessing the property of the constancy of the sum of distances (h) from any point to its sides and the property of ratios preservation $h_1 : h_2 : ... : h_{n+1} = a_1 : a_2 : ... : a_{n+1}$. Distances h_i are calculated on the basis of coefficients $a_i (i \in 1,2,...,n+1)$ and normalization operations from following relations (1):

$$\begin{cases} H = \sum_{i=1}^{n} h_i \\ H = A \sum_{i=1}^{n} a_i \\ \frac{h_1}{a_1} = \frac{h_2}{a_2} = \ldots = \frac{h_n}{a_n} \end{cases} ,(1)$$

where A is a scaling coefficient defined by the formula: $h_i = A \cdot a_i$, where $i \in \{1,2,...,n\}$.

The main function of n-simplex is representation of a disposition of object under study among other objects of a learning sample (Yankovskaya, 2011b). Additionally, n-simplex has other useful functions for a decision-making person. One of these functions is a representation of some numerical values, for example, an admissible error of recognition preassigned by the user. Example of 2-simplex is shown in Fig. 3, a.

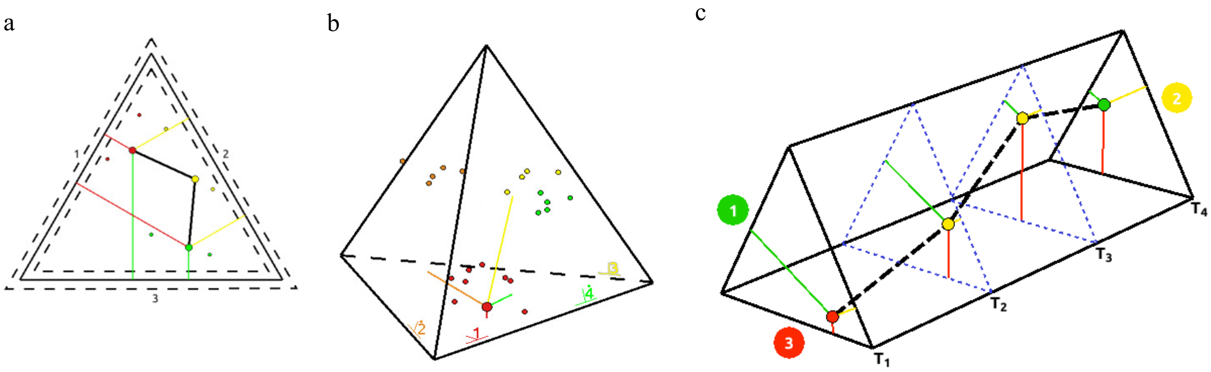

Fig. 3. (a) example of 2-simplex; (b) example of the 3-simplex; (c) example of 2-simplex prism.

The sides of 2-simplex (triangle edges) are associated with patterns (classes), circles with big radius are the objects under study and circles with small radius are learning sample objects. The distance from the object to a side is directly proportional to the proximity of the object to the pattern corresponding to the side. The distance for object under study is displayed as color perpendicular lines to 2-simplex sides (red, yellow, green). The color of the object under study or objects from learning sample is mapped to a pattern which is revealed for a specific object. Line segments between objects represent the dynamics of process under study, for example, they can represent changing of a student knowledge level. An object color is mapped with an associated pattern (the nearest pattern or pattern determined by an expert). Digits are mapped with a pattern and are placed on associated sides. It is not usual working mode because it makes the image more complex, and it is not necessary because the association between the side and the pattern can be determined by a color of the perpendicular line from the point to the side. So, for usual working mode it is suggested to hide these digits. But for the first look or demonstration it can be quite useful.

In LTIS 2-simplex prism allows represent result of a test for a respondent or a group of respondents related 3 patterns. Unfortunately, this tool can represent learning dynamic only in quite reduced form. This limitation was removed in a cognitive tool 2-simplex prism which will be described later.

A cognitive tool 3-simplex is development of cognitive tool 2-simplex with usage of 3D-graphics (Yankovskaya, et al., 2014 a, b). It is also appropriate to use both for decision-making and decision justification as well as to solve some of the following problems in LTIS. Example of cognitive tool 3-simplex is shown in Fig. 3, b.

Since Fig. 3, b displays the objects related to the four patterns, both the objects belonging to the corresponding pattern and the patterns are painted in different colors for better perception: *pattern 1*, corresponding to the lower edge is painted in red; *pattern 2*, corresponding to the near left edge is painted in orange; *pattern 3*, corresponding to the distant edge is painted in yellow; *pattern 4*, corresponding to the near right edge is painted in green.

Description of 2-simplex objects is also right for 3-simplex. Because this tool uses 3D-graphics, additional notice should be introduced: points over the pattern numbers 2, 4 indicate that these 3-simplex edges are visible.

The use of the 3-simplex allows to analyze the object under study for four patterns simultaneously, which is important for some subject areas, such as assessment of learning results in LTIS, when using points 2, 3, 4, 5, which cannot be achieved by applying the 2-simplex.

An important advantage of 3-simplex is a clear visualization of the dynamics of the process under study and visual comparison of the dynamics of different processes. However, a 3-simplex has a disadvantage compared to 2-simplex, as it may lose its visibility when displayed in the printed version, which lacks the possibility of interactive angle change available on the monitor screen.

The cognitive tool “2-simplex prism” (Fig. 3, c) is based on 2-simplex and represents the right triangular prism containing in basics and cross-sections 2-simplexes which correspond to fixed time moments.

Distance for the basis of the prism to *i*-th 2-simplex h_i' corresponds to the fixation moment of object under study features and it is calculated based on the following formula (2):

$$h_i' = H' \cdot (T_i - T_{\min}) / (T_{\max} - T_{\min}), \quad (2)$$

where H' is length of 2-simplex prism preassigned by a user and corresponded to the investigation duration, T_i is the timestamp of features fixation of object under study for *i*-th examination, $T_{\min}$ is the timestamp of features fixation of object under study for 1-st examination, $T_{\max}$ is the timestamp of features fixation of object under study for last examination. Description of all 2-simplex objects is also right for 2-simplex prism.

7. Conclusion

The MDT application in blended learning for estimation of knowledge, professional and personal skills and abilities are proved to be effective. LTIS with cognitive component is proposed to solve this problem. The proposed approach provides designing of an individual learning “trajectory” for each student. Such a trajectory is especially important since it allows personalizing the learning process, thus increasing its efficiency. LTIS is intended for students learning and testing, assessment of learning results and learning dynamics.

The background, the formulation of the problem, the method of MDT construction are given. The proposed mathematical basics of LTIS construction allows to reduce time for carrying out learning and testing and to motivate students on studying didactic units during a semester.

Application of fuzzy logic and threshold function increases accuracy and quality of an estimation of respondents (students). This blended approach will be used for learning, training and testing students of different courses, for example, mathematics, information technology, geoinformation systems, mathematical modeling, etc.

Cognitive tools application for problem under study allows making and justifying decisions about learning results at fixed time moment or in time interval unlike any of the previously developed cognitive tools based on n-simplex.

Approach used in LTIS increases effectiveness of blended learning by choosing the shortest ways to get the correct result and exclude the possibility of achieving it at random path.

It is planned to apply the methodology to the development of MDT for other courses with different internal structure. Eventually, this approach might be used as well in the practical sections of technological disciplines of engineering education, for example, in the course "Mathematical modeling". MDT can be formed in such a way that it would serve as a teacher to explain the procedure of solving complex practical problems.

2-simplex prism allows to investigate objects dynamically on the time range interested for a user.

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