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Learning Management System "VECTOR"

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Abstract
The article summarizes the major premises and goals for building a modern software system, which will support student learning and academic performance rating processes. It covers the testing quality evaluation system and describes how the data is loaded into the Learning Management System using the SCORM standard. The article includes such issues as authorization and audit for the Learning Management Systems. In particular, it describes an approach based on the role access policy. The article also demonstrates the videoconferencing module that enables to hold webinars using audio and video communication.

Keywords: Distance Learning, Academic Performance Rating, Electronic Tutorials, Webinars, Videoconferences, Authorization, Audit, Role System, SQL, SCORM.

Distance learning in the education is increasingly gaining popularity. It is widely used both in educational institutions and in enterprises and IDC data shows that it will come up with the traditional education with its popularity rating pretty soon [1]. Most higher educational institutions have distance learning centers, upon graduation from which a certificate is issued. To complete such distance learning you just need a computer and Internet access.
Today distance learning holds a strong position in the education field, which is a worthy replacement for the traditional education. In recent years there have been sweeping changes in the labor market: personnel qualification requirements have increased, IT technologies are implemented almost in all activities and the workforce itself has become more mobile. These changes made it necessary to create conditions for the continuous, fast, flexible, and at the same time high-quality personnel training, and it became necessary to search for alternative systems as the traditional educational systems are not able to meet these requirements.

RESEARCH OBJECTIVE

The objective of designing and developing a universal testing and learning system, which would also allow monitor the academic performance rating, was set more than a year ago. The first version of the "Vector" system was introduced as a result of the work done. This system is marketed as a tool for academic teaching staff to automate the teaching process and introduce monitoring activities. This software package has been put into a trial operation. However, in the course of work with this complex it was found that it does not implement all the functions required for teachers. Consequently, it was conducted the analysis, on which basis it was made a decision to add new modules to the system.
The system design was carried out based on the requirements and requests of the end users-students and teachers of the National Research Nuclear University "MEPhI" University. Requirements gathering was carried out through interviewing end users and all requirements were gathered in a single document. As a result, we have determined the core needs of the target audience, which made it possible to identify the directions of system expansion through the development and implementation of additional modules.

TESTING QUALITY ASSESSMENT

The possibility to continuously improve the quality of the educational process is the primary goal of this system building and therefore this brings up a critical issue on improving the created tests. The research in this area resulted in the construction of Item Response Theory (IRT)-a theory that appeared on the basis of biological studies, and which improves the measurement accuracy as compared with the classical test theory, and also optimizes the monitoring procedures by adapting tests to the student training level.
The idea behind this theory is to measure the students' latent qualities (not subject to direct measurement) using the empirical results [2]. The means of influence, the response to which can be measured directly, are called indicators, and the core IRT task can be formulated as a transition from the indicator variables to the latent parameters [3].
The IRT practical application is to determine the students' training level and test item difficulties according to the test results.
The answer to the second question, being the core IRT issue, is associated with the choice of mathematical model to describe the relation between the latent parameters and monitored test results.
Especially, we can view the conditional probability of correct execution of i-test subject with competence level q_i of different test tasks depending on the complexity level, assuming q_i as a parameter of i-student, and b as an independent variable. In this case the conditional probability is a function of latent variable b:

$$P_i\{x_{ij} = 1|\theta_i\} = f(\theta_i - \beta), i = 1, 2, .., \mathrm{N} \quad (1)$$

Here, x_{ij} = 1 if the answer of thei-test subject to j-task is correct; x_{ij} = 0 if the answer of the i-test subject to the j task is incorrect.

Similarly, the conditional probability of the correct execution of the j-task with difficulty $b_j$is introduced in various test groups. There is an independent variable q, and b_j is a parameter that determines the difficulty of the j-test task:

There are three basic models of the modern test theory:

$$P_j\{x_{ij} = 1|\beta_j\} = \varphi(\theta - \beta_j), j = 1, 2, .., n \tag{2}$$

We will use a one-parameter model developed by G. Rasch:

$$P_j(\theta) = \frac{e^{1,7(\theta-\beta_j)}}{1 + e^{1,7(\theta-\beta_j)}} \tag{3}$$

$$P_i(\beta) = \frac{e^{1,7(\theta_i-\beta)}}{1 + e^{1,7(\theta_i-\beta)}} \tag{4}$$

So, to calculate the theoretical probability of a correct answer to the task, it is required to evaluate the following parameters:

- q-level of subject proficiency
- b-level of task complexity

It is possible to do using the mathematical tool IRT and on the basis of simple statistical considerations.

The test is ideally balanced in terms of task difficulty if

$$\sum_{j=1}^{n} \beta_j^0 = 0 \tag{5}$$

The education test as a tool for assessment of educational achievements can provide reliable results only subject to its correct application. Thus, the noncompliance of empirical data of the Rasch model means that there are inaccuracies in the task formulations, failures in the test procedure, etc.

When analyzing the test results, it is required to check the conformity of the empirical data, calculated according to the Rasch model. To do this, all *N* test subjects, fulfilling *M* test tasks are classified on a θ scale depending on their level of c proficiency [4]. The test subjects are divided into *J* groups along the θ scale and all test subjects within the group have the same level of proficiency θ_j. The total number of *j* group will include m_j test subjects where *j* takes values of*j* interval = 1, 2, 3,..., *J* .

In each group, r_j test subjects respond correctly to this test item. Thus, for a competence level equal to θ_j the probability of correct answer to this task is the following

$$p(\theta_j) = \frac{r_j}{m_j} \tag{6}$$

where r_j is a number of subjects that gave correct answers to the task within j group, m_j-number of students included in the j-group, j = 1, 2,..., J, $p(\theta_j)$-experimental probability value of the correct answer to this test item. Further it is required to check how well the model describes the empirical data. The conformance testing of the H_o hypothesis to the empirical data of the one-dimensional IRT model for all test items is carried out on the basis of the criterion χ^2 [5]:

$$\chi^2 = \sum_{j=1}^{J} m_j \frac{(p(\theta_j) - P(\theta_j))^2}{P(\theta_j)Q(\theta_j)} \tag{7}$$

where $p(\theta_j)$ is an experimental probability value of the correct answer to this item, $P(\theta_j)$-theoretical probability value of the correct answer to this item, calculated according to the Rush model, $Q(\theta_j)$-theoretical probability value of the incorrect answer to this test item.

The calculated value χ^2enables to identify the degree of conformity of the experimental data to the Rasch model. It is used to calculate the α-quantile value, which is between 0 and 1. The closer is the α-value to the unit, the better is the interaction between the experimental and theoretical data, calculated pursuant to the model, and vice versa. The critical value is considered to be equal to 0. 05. The number of degrees of freedom is equal to J on calculation of the theoretical value. The quantile is calculated on the basis of these values and used to determine whether the experimental data is consistent with the theoretical data.

"Vector" system allows a teacher receiving various reports on students test passing. This includes a detailed test report, a report on student or group progress, and an overall progress in the discipline. The reports on the test quality were also included in that list. Thus, the system enables to estimate the complexity of each test issue, and demonstrates a teacher, which test items need to be left, and which ones-to be excluded. In addition, the system gives an overall assessment of the whole test in terms of requirement of its improvement. All conclusions on the test quality are drawn on the basis of the methods and techniques of the Item Response Theory, as described in this article.

LOADING SCORM OBJECTS

The core issue of the distance learning is system dependence on the teaching materials, namely the medium, which they were developed in. "Vector" system is a universal system of distance learning, which uses universal educational information resources. "Vector" system meets the requirements of the SCORM standard.

SCORM is a set of interrelated specifications and standards. Almost all of them have been developed previously by other companies and then summarized within the SCORM. Currently SCORM standards are divided into 3 groups:

*Content aggregation model(CAM)*describes the components of educational materials in accordance with the SCORM standard, component ordering rules, means of their interaction, and also describes the rules for their search and launch.

Run-time Environment (RTE) describes the requirements to LMS (Learning Management System), and specifically what properties LMS shall have and what methods it shall support. The methods are used to exchange data between the system and training materials. RTE objective is to provide content independence from the LMS.

Sequencing and Navigation Model (SN) describes how the learning material shall be organized. Organization means laying out the parts of the learning materials while attending a curriculum.

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According to the standards as set forth in the IMS (CAM model), the educational resources are described and packaged using XML format. The materials are presented in the form of independent package that consists directly of content and manifest. The manifest is a mandatory part of the package and it is in XML file named "imsmanifest. xml". The manifest describes the attached manifests, resources, information on the structure of educational materials, and metadata. The content (resources) may be in different files (audio, video, images, text files, presentations, etc.)

When describing the resources, the list of used resources is described. In other words, resource is a set of references to the files used by it, and one of the files is specified as the core file to be used to start the display. The educational materials can be combined or summarized with submanifests, giving a reference inside one manifest to another manifest.

As a result, all resource files and the manifest file form a SCORM package, and the manifest file must be in the root package directory. These files are packaged into a PIF file. The ZIP archive is used as a format for the PIF file.

A load module has been developed to upload the data described pursuant to the SCORM standard. It is first required to upload the SCORM package to the system. The system will analyze the uploaded package, i. e. the manifest file "imsmanifest. xml", and will offer a user the content that can be uploaded into the system. Different types of questions may be uploaded into the system such as: a question with a video or a picture with a multiple answer choice. Then it is possible to preview the content before uploading. The module also enables to compose the uploaded questions in the test, or add them to the existing test.

VIDEOCONFERENCING

When moving from the traditional modes of study to the distance ones, it is important to adopt the positive aspects of the traditional education as much as possible. The absolute advantage of in-class learning is that a student can ask a teacher his question any time, and the teacher, in his turn, can get quick feedback on any difficulties the students might have had and explain the material in more detail. All this is an absolute advantage of the traditional education and facilitates a better learning of the material.

Having analyzed the said aspects of in-class learning, it was made a decision to develop a videoconferencing module for the learning management system "Vector". This module is designed to eliminate any disadvantages of distance learning through adding the element of real-life communication, which will enable to achieve higher levels of learning alongside with the LMS options, rather than the common in-class learning.

The following requirements are made to the videoconference module: a support of voice and video communication, messenger (chat), an interactive whiteboard, a poll option, a user privilege control option, a presentation and text document view option, an option of file interchange between the participants, as well as a conference record option.

Analyzing the requirements to the module, as well as the existing solutions for videoconferencing, it was made a decision to integrate the videoconferencing system OpenMeetings (http://openmeetings. apache. org) into the LMS system, as it meets all the requirements, has a well-designed API, enabling to get a total control over the system operation, and an intuitive interface, which is very important for users who are just beginning the transition to distance learning.

The lessons using the video conferencing system are called webinars, which take place in so-called rooms. The OpenMeetings video conferencing server is fully controlled by the LMS, which automates the room control process, and gives privileges of room moderator within the video conferencing system depending on the user's role in the LMS. When entering a room, the system sets automatically a user name to be used in the LMS, and carries over his avatar. This is all used for the videoconferencing systems to prevent any difficulties for unprepared users.

Video conferencing rooms can be created from the course page by any teacher that they are assigned to. To create a room you need to specify the name and description of the room, and some parameters of the room itself (need for a whiteboard, chat, screen demonstration option, etc.). Then the LMS "Vector" will create a room within the OpenMeetings system. All information about the created rooms is stored in the LMS. It helps to facilitate the system migration to a different server and allows the system to restore automatically a set of rooms in case of failures in the OpenMeetings server operation (both software and hardware).

The entrance to the room is made from the respective section of the course page. When entering the room, all teachers are given moderator privileges, while students do not have such rights. The moderator has a right to draw on the interactive whiteboard, display a screen, speak in the voice chat, demonstrate images from his camera, and may grant any such rights (including granting moderator's rights) to students that allows flexible management of the webinar (e. g. imitate a call to the board for one of the students, which is possible subject to giving him a right to draw on the board and use a microphone).

Using the video conferencing system absolutely enhances the capabilities of the learning management system, and it is worth considering that the use of video conferencing server increases the server hardware requirements. As the minimum system requirements made to OpenMeetings are 1GHz CPU, 1 GB RAM, document converters, recorders and upload feature will not be available in this case. In order to use any options of the video conferencing system, the system has to meet 2x/4x 2GHz CPU, 4GB RAM requirements. To operate OpenMeetings it is required JRE 7/8.

Summarizing the video conferencing module features, it is worth to say that it is designed to bring online learning as much as possible in line with the in-class learning, incorporating all advantages of both Learning Management System, and in-class lessons.

ROLE SYSTEM

It is required to solve authentication and authorization issues sooner or later for any information system, involving human interactions. It is necessary to distinguish these two concepts. The authentication will be further considered as the user identification and authentication process. The authorization will be considered as the user authorization process to perform various activities in the system. Typically, these processes are treated independently. However, authorization always assumes a correct authentication outcome. Subsequently, the authentication issues will not be covered.

There are 3 basic access policies for the authorization systems in today's information systems: discrete, mandatory and role-based [6]. It is typical to provide a large number of similar users (students) with relatively little changing privileges for the Learning Management System, while the major part of the functional is intended for teachers. These features require a maximum flexibility of the authorization system.

The role system helps to solve the authorization issues. As the name implies, the role system is based on the role-based access policy and follows the principles typical for that policy [6]. The studies confirm that the role-based policy is a useful approach for many commercial and government organizations [7]. The role can be defined as a set of actions and duties associated with the user's specific activities in the Learning Management System. The roles system requires a preliminary identification for each particular role in the system. This identification is done by the system administrator.

All objects in the Learning Management System, including functions make a certain hierarchy and may be represented as a tree. This is a three-level tree in the context of the teaching and academic performance rating system. The leaves of that tree are elementary user functions (view schedules of certain teachers or edit news). The intermediate level corresponds to the major subsystems (schedule module, news module, etc.). The top level (root) is represented throughout the entire system. Thus, each role can be represented as an unorganized set of tree leaves.

To ensure a better flexibility and adaptability to the changing requirements and functional, each role includes a minimum set of functions, preserving the logical role integrity in accordance with the principle of least privileges [6]. However, the experience has shown that this solution is not really suitable for a large number of users from the point of administration view. For this purpose, the role group concept was introduced, i. e. a stereotype, accumulating some of the most typical roles for certain types of users. Formally, the role group can be represented by an irregular set of roles forming it.

The Learning Management System is focused on different participants of the educational process (teachers, students, assistants, etc.), which implies the availability of the functional, dealing with the information that may be available in some participants and not available in others (e. g. a teacher may not have a group number). And according to the duty separation principle [6], special limitations are introduced at the function level, which do not allow including such diverse functions in one and the same role.

The above hierarchy is stored in a relational database. Database indexing is provided by self-balancing trees (in particular, red/black trees) that ensures a logarithmic search complexity. It is provided caching of the functions enabled to a user during the session to raise performance. Session means sequence of user queries, between which a maximum time interval is set.

The access check occurs twice: when a page is displayed (at the level of specific controls such as buttons, links, etc.) and on direct system function queries.

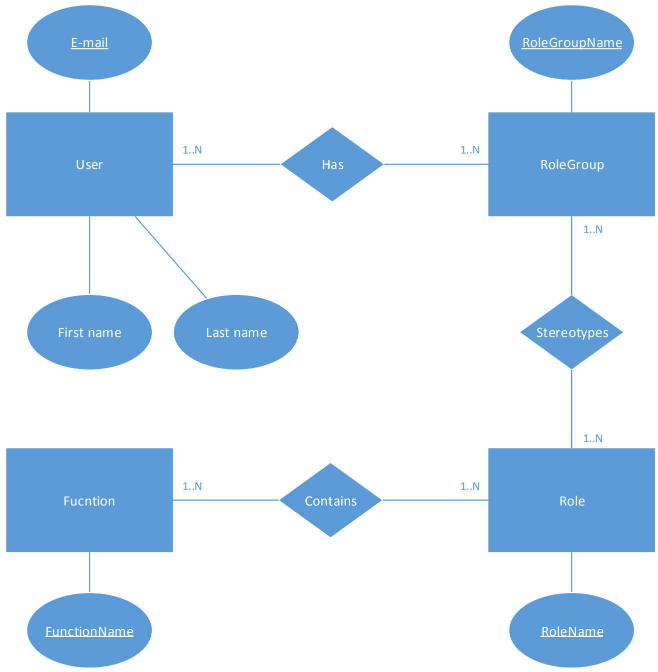

Figure 3: ER-diagram of the role system (Chen notation)

AUDIT

One and the core objective of the audit is to show what action has occurred in the system, at which point it was called, who initiated it and what consequences it resulted in. The audit system exists in the liaison with the authorization system and helps to establish the correctness of the latter. It is demonstrated that only authorization systems without the corresponding user action locking are not sufficient for efficient access control [6].

The Learning Management System functional can be represented as a tree, which leaves are the basic functions of the system. It is enough to fix, which of the above elementary functions the user took advantage of, to audit the actions. Thus, the user action fixation task is reduced to the task of fixing the functions provided to the user by the role system.

Any state changes of the learning management system objects are carried out within a single user query. In practice, each query corresponds to a specific function of the system. And to fix the changes of the system objects it is enough to fix which system contents were affected by the user action during the processing of his query. It is proposed to use an object, i. e. query context that is common to different layers of the learning management system architecture.

In fact, the audit information shall be gathered and stored in a single repository. The multi-threaded program will need to synchronize entries in that repository. It is suggested to use a message queue. File recording only occurs when the queue is filled with the number of messages preset by the administrator. This enables to reduce the number of accesses to the file system and to reduce end user waiting for a response to the system query. The queue itself is in the object that implements the design pattern "singleton" [8].

The design pattern "singleton" requires special synchronization. Otherwise, this often results in the troubles with the use of internal buffer. One of the best ways to solve this trouble is to use the so-called double-checked locking [9], which is a template for optimizing unnecessary lockups. The template means testing some conditions twice before attempting to enter the synchronized code block and directly before the lockup on the entry to the synchronized section.

The audit information is stored in binary files with a special structure. This enables to reduce the load in the operational database. Each file corresponds to a specific date. Such approach allows archiving the files not used for recording, on the one hand, and maintain only one original (uncompressed) file, which is recorded in this day, on the other hand. The first 128 bytes of each file are reserved for the meta-information, including the message length (bytes in positions 1-4), signals of system audit log completion (special byte in the 0th position). Starting from the 128th position, the serialized audit log messages are stored.

It was carried out a load testing, which was mainly focused on measuring the message recording and reading capacity. The testing was done in 100 flows to record and read 1 million messages of the audit log. If the queue is not used, 1 million messages are recorded for less than 10 seconds, and if the queue is used, the messages are recorded for about 30-40 seconds. This is due to the time spent on opening and closing the files. To speed up the recording, it is necessary to increase the queue size, but it also increases the read latency of the relevant audit information.

CONCLUSION

This article summarizes the basic aspects of the creation of new modules for the "Vector" system, which is designed to automate the learning process and follow-up activities. This system is designed to be used mainly in various educational institutions that will simplify the learning process both for students, and for teachers. At the same time, this system may be used as the learning management system due to the available system modules, and it can be easily modified to meet any requirements.

The modules of the "Vector" system cover a wide range of functions that enable to perform the following tasks:

- create and pass tests;
- create and edit training courses;
- create, upload and check the task database;
- create meetings;
- monitor attendance;
- deal with different reports;
- evaluate test quality;
- load SCORM objects;
- use videoconferences in the learning process;
- manage the roles of system users;
- audit.

Thus, these modules help teachers and students in the learning process, and they also provide ample opportunities for the administration of the "Vector" system, which may improve the quality of the educational process with the use of this system, as a whole.

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