Fuzzy model for evaluating the results of online learning

Veronika Zaporozhko, Vladimir Shardakov and Denis Parfenov
Orenburg State University, ave. Pobedy 13, Orenburg, 460018, Russia

E-mail: shardakov_vm@mail.osu.ru

Abstract. The article is devoted to the development of a fuzzy model for an integrated assessment of the results of mastering the contents of the curriculum of an online course. It is determined that the mathematical apparatus of fuzzy logic and fuzzy inference is an integral part of the decision support system for the intelligent management of individual educational trajectories in an online learning environment. It is described how the presented model can be used for decision making under conditions of uncertainty and fuzzy given initial data circulating in an online environment. The technique of integrated assessment of the results of online learning using the application package "Fuzzy Logic Toolbox" for MATLAB is shown. The calculation results are presented using an example of a real online course. The proposed model can be used to modernize the system of objective assessment of educational achievements in online courses and introduce the intellectual management of individual educational trajectories into the practice of online learning.

1. Introduction

An online learning system in which a person is active is characterized by high complexity and dynamism, which greatly complicates its modeling using well-known mathematical expressions. Teachers and students are more accustomed to describe the processes that occur in the environment of online learning, in verbal, informal, form. In the future, in order to build a mathematical model, human judgments described in natural language can be interpreted on the basis of fuzzy sets, which formally define inaccurate, ambiguous, and vague concepts. Fuzzy logic, as a model of human thought processes, fits well into automated decision support tools. In particular, the authors suggest using it when creating a system of intellectual control of individual educational trajectories in an online learning environment. The presence of a mathematical apparatus for reflecting the fuzziness of the available initial information will allow us to build a given model that is adequate to reality.

2. Literature review

Currently, educational information systems are actively developing. One of the main tasks requiring automation is the development of various mechanisms for evaluating the results of studying educational programs. Moreover, methods and approaches based on the theory of fuzzy sets are increasingly being used.

Thus, a group of researchers led by A. Burlybayev proposed a model for assessing performance based on fuzzy rules. The advantage of this approach is a qualitative assessment of the level of knowledge based on competencies without the use of complex calculations to determine points for each completed task in the framework of the studied discipline [1].

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In a study by Michael Gr. Voskoglou based on the theory of Fuzzy Relation Equations developed a model for assessing students' skills in the field of Mathematical Modeling. Researchers compare the proposed solution with models based on the average student score in the group. In practice, an estimate based on fuzzy equations of relations has shown a more accurate result [2].

The research work of scientists from Nigeria is aimed at developing an entire expert system based on fuzzy logic for predicting student performance at Adamawa State University. The authors use the Fuzzy Inference System in conjunction with the Gauss membership function. Experimental studies in the environment of MATLAB show that student performance can be predicted with an accuracy of 90% [3].

The apparatus of the theory of fuzzy logic can be used not only directly to assess academic performance, but also to assess the impact of students' achievements obtained during the development of educational programs on the learning outcomes of specific courses. Çetin Semerci in his study compares traditional methods of assessing achievements with achievement estimates based on the theory of fuzzy logic [4].

Several approaches can also be used to formulate the rules of assessment themselves. So, Ibrahim A. Hameed proposed the Fuzzy Linguistic Hedges method, which allows to expand the contrast of the fixed form of fuzzy sets and, therefore, to more accurately form the final grade within the studied subject area [5].

In [6], the concept of using artificial intelligence methods based on the use of fuzzy logic theory to calculate the final grade for a course is developed. The author of the project proposes to integrate the system of grades received for the course with other factors affecting the result of studying the chosen course. This allows you to increase the effectiveness of the assessment system and fully assess the potential of the student in the implementation of practical work in the discipline.

As can be seen from the presented studies, the assessment of student learning outcomes is an important and multifaceted task. To ensure the objectivity of the assessment it is necessary to use many factors. A set of factors affecting the final grade for a course is usually determined by the course author or teacher. Moreover, the factors used do not take into account the peculiarities of studying the material by the students themselves. In their study, Jian Ma and Duanning Zhou propose an approach based on the theory of fuzzy logic, which eliminates this imbalance. The proposed approach is aimed at encouraging students to participate in the entire learning process and provide an open and fair environment for assessment [7].

Active involvement of students in the educational process is developing in the Outcome Based Education (OBE) methodology. The OBE approach encourages students to become active students, rather than passive, as in the traditional teacher-centric approach. A study by a research team led by Abraham Varghese presented an effective way to evaluate course outcomes using fuzzy logic. The uniqueness of the method lies in the fact that it allows you to get the exact measure for assessing the level of course completion, considering each parameter that provides the learning process [8].

A study by Meenakshi and Pankaj Nagar proposes another classifier of factors influencing the estimate obtained on the basis of fuzzy logic methods. The authors distinguish three parameters: attendance, internal and external assessments that students receive in the learning process. The developed expert system using fuzzy logic based on the Mamdani method showed the best result [9].

Thus, a review of research on this topic showed that the application of the mathematical apparatus of the theory of fuzzy sets is an actual area of research in this area. Nevertheless, there is a problem of choosing effective criteria on the basis of which estimates of the results of studying the content of the course programs are formed. In the framework of this study, we propose to use the fuzzy inference apparatus for an objective and balanced assessment, as well as the formation of a system of recommendations for adjusting an individual educational trajectory in the framework of studying online courses.
3. Methodology for a comprehensive assessment of the results of studying the content of the curriculum of an online course

A. Basic concepts of the theory of fuzzy sets

The theory of fuzzy sets is associated with the introduction of linguistic variables that describe the inaccurate (fuzzy) reflection of a person around the world. Fuzzy sets were first identified by Professor Lotfi Zade, who published an article in 1965 titled "Fuzzy Sets" in the journal Information and Control [10].

The concept of fuzzy sets is the formalization of fuzzy information for constructing mathematical models. The basis of this concept is the idea that the elements making up a given set with the common property can possess this property to a different degree and, therefore, belong to this set with a different degree. With this approach, statements like "such-and-such an element belongs to a given set" lose their meaning, since it is necessary to indicate with what degree (how much) a particular element satisfies the properties of a given set. The theory of fuzzy sets allows the statements "low student performance" or "high average mark" to give a specific mathematical meaning. Thus, in a number of situations, it becomes possible to reduce the qualitative assessments of teachers and students to quantitative, numerical (albeit fuzzy).

Fuzziness is understood as a type of uncertainty that arises due to the problem of separation of the boundaries of various characteristics of entities in view of the subjectivity of this assessment.

A fuzzy set is a collection of elements of an arbitrary nature, regarding which it is impossible to precisely state whether these elements have some characteristic property, which is used to specify a fuzzy set.

For calculations on fuzzy sets, the apparatus of fuzzy logic is used, which allows the concept of uncertainty to be used in logical calculations.

B. Using fuzzy logic for decision making under uncertainty

As part of a series of studies, we have designed a hybrid intelligent system. This system is integrated into the online learning platform and allows you to dynamically generate and adjust an individual educational path for each student. One of the program modules of this system is responsible for a comprehensive assessment of the results of mastering the contents of the curriculum of an online course based on the mathematical apparatus of fuzzy logic. Since online learning systems are characterized by high complexity, in which an active person leads, its modeling with the help of well-known mathematical expressions is significantly complicated. In this system, there are uncertainties and vagueness in the existing data, therefore, based on the theory of fuzzy sets and fuzzy logic, it is possible to build the desired model that is adequate to reality.

C. Methods for evaluating the results of mastering the content of the curriculum of an online course

Given the practical importance of assessing the results of educational activities of students in online learning systems, teachers use two main methods: automated test control and written control.

The objectivity of the test results is achieved by ensuring the internal substantive validity of the test and the exclusion of subjective factors in the process of its design and implementation, interpretation of control results.

When conducting written control, there is often subjectivity on the part of the teacher and the ambiguity of the object of assessment. The implementation of the competency-based approach provides an opportunity to solve this problem and involves the transition to a substantive-criterion basis for evaluating the results of mastering the contents of the curriculum of an online course. Careful development of assessment criteria (success criteria) contributes to the objectivity of the assessment procedure. Evaluation criteria are determined by the objectives of the training and are a list of the student’s activities that he carries out during the work and must master it as a result of the work. With this approach, the subjectivity of the teacher is excluded or manifests itself to a lesser extent.

According to the authors, a comprehensive assessment of the results of mastering the content of the curriculum of an online course should consist of several components, namely assessments for three groups of results:
• mastering the theoretical part of the course, identified using automated test verification for each topic of the course;
• mastering the practical part of the course, that is, activity tasks (practical work, projects, essays, etc.), assessed by the teacher manually using pre-developed and clearly formulated criteria known to the student;
• the mutual evaluation of a number of works by other participants in the course based on clearly formulated criteria that can be offered by the teacher in a finished form or developed jointly with a group of students.

It is assumed that the assessment for all selected groups will be "transparent", understandable and take place online, and the results will be dynamically aggregated in an intelligent system integrated into the online learning platform. The information received will be available to both the student and the teacher. The confidence of students that within the framework of a single online course ensures equal conditions for a fair assessment of the results of educational activities, there are the same evaluation criteria and the maximum possible exclusion of subjective attitude on the part of the teacher is guaranteed, this is a significant incentive to master the full content of the curriculum.

D. A meaningful statement and a formalized description of the task of a comprehensive assessment of the results of mastering the content of the curriculum of an online course

Let the content of the online course be represented by n topics. The system of assessment procedures provides for the implementation of the test and activity assignment in each topic, and, if desired, the mutual evaluation of the submitted works. Then, for the group X.Test ("Automated test control"), the variables \((x_1, x_2, \ldots, x_n)\) will be the input; for the group Y.Instructor ("Teacher") the variables \((y_1, y_2, \ldots, y_n)\) will be the input; for the group Z.Listeners ("Students of the course") the variables \((z_1, z_2, \ldots, z_n)\) will be the input.

The output variable X.Test ("Automated test control") has input variable values (input variables): \(x_1\) is the result of the test control in topic 1; \(x_2\) is the result of the test control in topic 2; \(x_n\) is the result of the test control in topic \(n\).

Let us describe the output variable Y.Instructor: the teacher evaluates the activity task according to a number of criteria in each topic: \(y_1\) is the result of the task assessment in topic 1; \(y_2\) is the result of evaluating the assignment in topic 2; \(y_n\) is the result of evaluating the job in topic \(n\).

We define the output variable Z.Listeners: the course participants mutually evaluate the submitted works according to a number of criteria in each topic: \(z_1\) is the result of evaluating the work in topic 1; \(z_2\) is the result of evaluating the work in topic 2; \(z_n\) is the result of evaluating work in topic \(n\).

For each component ("Automated test control", "Teacher" and "Students of the course") we will assign a certain weight (significance) to its integral assessment.

The proposed integrated approach to the procedure for an objective assessment of the results of mastering the content of the course of an online course involves the use of the mathematical apparatus of the theory of fuzzy sets and fuzzy logic. A fuzzy conclusion is used to make decisions in the face of inaccurate, ambiguous, and vague information coming from students and teachers when they interact in an online environment. One of the key ideas of this approach is that work is carried out with numerical values that are input and output, and at the intermediate stages, a fuzzy logic apparatus is used. As a result, it turns out that operations are performed on numerical data, but at the same time, the flexible capabilities of the mathematical apparatus of fuzzy logic are used. Thanks to fuzzy logic, ideas about management and decision-making processes in the online learning environment are well laid out. A higher degree of granularity can lead to a reduction in the volume of processed and stored large amounts of data and to increase the speed of algorithms.

Depending on the results of a comprehensive assessment and their interpretation (table 1), dynamic adjustment of an individual educational path and the implementation of an intellectual recommendation system became possible. Namely:

• if the level is "Poor", then the student will be recommended to take the course again;
if the level is "Average", the student will be asked to re-examine those topics on which significant gaps have been identified;
if the level is "Good", then the student will be recommended to study the expanded content of those for which difficulties are identified;
if the level is "Very Good", then it is considered that the development of the program is completed, and it will be recommended to study some additional sections that expand and deepen the program of this course;
if the level is "Excellent", then it is considered that the development of the program is completed in full, and it will be recommended to study new courses in the related field or take a professional intensive course in this field of knowledge.

| Table 1. The term set of all possible values of the linguistic variable R. |
|-----------------|----------------|----------------|----------------|----------------|----------------|
| Final Result    | Poor (Failed/ | Average (Sat- | Good          | Very Good      | Excellent      |
| (Output)        | Unsatisfactory) | isfactory)    |                |                |                |
| Result          | 0-49           | 50-64          | 65-74          | 75-84          | 85-100         |

Before testing the functional performance of the created software module, we conducted a computational experiment to test the proposed methodology for solving the problem using the Fuzzy Logic Toolbox extension package for the MATLAB software product. This package contains the necessary tools for designing fuzzy logic systems.

4. Proposed fuzzy model
A. Model description

Three components were used as input variables:

- X.Test – results of automated test control ("Automated test control");
- Y.Instructor – the results of a written control of student completed activity tasks conducted by a teacher ("Teacher");
- Z.Listeners – the results of the mutual evaluation of the submitted works by students of a particular online course ("Students of the course ").

The output variable was the Result value "Comprehensive assessment of the results of mastering the curriculum of the online course", which is determined by fuzzy logic (figure 1). Fuzzy inference was performed using the Mamdani algorithm.

Figure 1. Definition of a comprehensive assessment of the results of mastering the contents of the curriculum of an online course using fuzzy logic.
The use of a fuzzy model for a comprehensive assessment of the results of mastering the contents of the curriculum of an online course and making decisions in the face of uncertainty consisted of the following steps [11, 12]:

- Fuzzification of the input values of X.Test, Y.Instructor and Z.Listeners and the output value of Result. Based on fuzzification, a numerical value is converted to a fuzzy symbol value.
- Definition of application rules and fuzzy inference algorithm. Fuzzy reasoning is fuzzy inference using unions and intersections.
- Defuzzification of the Result value. A clear decision is defuzzification, which is the conversion of a fuzzy symbolic value to a number.

B. Performance Evaluation with Fuzzy Logic

Consider the solution to the problem of comprehensive assessment of the results of mastering the contents of the curriculum of an online course. We conducted a computational experiment on the example of learners mastering the course "Modern means of evaluating learning outcomes", the structure of which is presented by five topics.

Before starting to compile a rule base for fuzzy inference, we describe the term-set of each linguistic variable under study. The basis for constructing the membership function used expert estimates.

When conducting automated test control, a 100-point rating scale was used (table 2).

| Final Result (Output) | Unsatisfactory | Satisfactory | Good | Excellent | Final Result (Output) |
|-----------------------|----------------|--------------|------|-----------|-----------------------|
| X.Test                | 0-59           | 60-75        | 76-89| 90-100    | X.Test                |

When assessing the results of students completing activity tasks, the instructor was guided by pre-developed evaluation criteria for each task in each individual topic. Then, according to the obtained criteria, points were set and levels were revealed (table 3). Similarly, the submitted work is evaluated by students of the course according to established criteria.

| Final Result (Output) | Unsatisfactory | Satisfactory | Good | Very Good | Excellent |
|-----------------------|----------------|--------------|------|-----------|-----------|
| Y.Instructor / Z.Listeners | 0-49           | 50-64        | 65-74| 75-84    | 85-100    |

The rules determine input and output membership functions that will be used in inference process [13 – 15]. These rules are linguistic and also are entitled "If-Then” rules. The rule base can be as follows (figure 2):

- If X.Test is Unsatisfactory and Y.Instructor is Unsatisfactory and Z.Listeners is Unsatisfactory then Result is Poor.
- If X.Test is Unsatisfactory and Y.Instructor is Unsatisfactory and Z.Listeners is Satisfactory then Result is Poor.
- If X.Test is Unsatisfactory and Y.Instructor is Unsatisfactory and Z.Listeners is Very Good then Result is Average.
If X.Test is Excellent and Y.Instructor is Excellent and Z.Listeners is Excellent then Result is Excellent.
If X.Test is Good and Y.Instructor is Very Good and Z.Listeners is Very Good then Result is Very Good.

![Active rules](image1)

**Figure 2.** Active rules.

Fuzzy inference visualization window presented in figure 3.

![Fuzzy inference visualization window](image2)

**Figure 3.** Fuzzy inference visualization window.

5. **Conclusion**

In this research work fuzzy logic toolbox using Fuzzy inference system has been used to design the system on MATLAB environment. Three inputs were used to submit to the system for one output. Different candidates were used to test the system, and the results show an accuracy of 95%.

The advantages of the proposed model based on fuzzy logic are as follows: 1) the fuzzy model is more understandable for the instructor than a similar mathematical model; 2) the method of fuzzy sets
allows you to include qualitative variables in the analysis, operate with fuzzy input data and linguistic criteria; 3) fuzzy models are easier to implement than other algorithms and methods of intelligent data processing.

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