UDC 65.015.12
DOI: 10.15587/1729-4061.2024.306183

CONSTRUCTION OF A FUZZY MODEL FOR MANAGING THE PROCESS OF FORMING IT-COMPETENCES

Kainizhamal Iklassova
PhD, Associate Professor
Department of Information and Communication Technologies*

Aliya Aitymova
Corresponding author
Senior Lecturer
Department of Theory and Methods of Primary and Preschool Education*
E-mail: aitimova_a_1985@mail.ru

Oxana Kopnova
Senior Lecturer
Department of Mathematics and Informatics*

Ainagul Sarzhanova
Senior Lecturer
Department of Theory and Methods of Primary and Preschool Education*

Gulmira Abildinova
PhD, Associate Professor
Department of Informatics
L. N. Gumilyov Eurasian National University
Satbayev str., 2, Astana, Republic of Kazakhstan, 010008

Agibay Kushumbayev**
Zhanat Aitymov
Teacher**
*Non-Profit Limited Company
«Manash Kozybayev North Kazakhstan University»
Pushkin str., 86, Petropavlovsk, Republic of Kazakhstan, 150000
**Municipal State-owned Enterprise
«Higher Construction and Economic College»
N. Nazarbayev str., 262, Petropavlovsk,
Republic of Kazakhstan, 150000

The relevance of this study is predetermined by the lack of models and algorithms for managing the formation of IT competencies in children of senior preschool age in the information and educational environment of a preschool organization. The object of the study is the process of managing the formation of IT competencies in children of senior preschool age. The problem under study is the need to build an effective system for assessing and managing the level of IT competencies, taking into account the uncertainty and subjectivity of assessments, as well as ensuring flexibility and adaptability of the process of developing competencies.

The constructed model based on fuzzy logic takes into account the uncertainty of assessments and decomposes competencies into indicators of achievement (low, medium, high levels). The production model of knowledge representation based on fuzzy inference rules enables control adaptability. As a result, recommendations were compiled for assessing and developing competencies taking into account the individual characteristics of children and the educational environment.

The approaches and tools proposed in this study help improve the quality of preschool education by providing teachers with effective tools for managing the educational process in the context of digitalization. The essence of the results is to build a model that makes it possible to integrate uncertain and subjective data into the process of assessing IT competencies, providing more accurate and objective assessments.

The results could be used in the information and educational environments of preschool organizations, as well as in education systems that introduce modern technologies for assessing and managing competencies

Keywords: fuzzy logic, IT competencies, adaptive educational environment, human capital, individualization of learning, digitalization of education, preschool organizations

Received date 01.04.2024
Accepted date 07.06.2024
Published date 28.06.2024

***How to Cite:** Iklassova, K., Aitymova, A., Kopnova, O., Sarzhanova, A., Abildinova, G., Kushumbayev, A., Aitymov, Z. (2024). Construction of a fuzzy model for managing the process of forming IT-competences. Eastern-European Journal of Enterprise Technologies, 3 (3 (129)), 32–43. https://doi.org/10.15587/1729-4061.2024.306183*

1. Introduction

In the context of the rapid development of information and communication technologies (ICT) and their widespread implementation in various realms of life, the formation of IT competencies in children of senior preschool age is of particular importance. Modern society requires a high degree of digital literacy from its members, which begins from a very early age. The relevance of this topic is due to the need to prepare the younger generation for life and work in the digital world, as well as to ensure equal opportunities for all children in access to quality education.

Research in the field of developing IT competencies in preschoolers is important for several reasons. First, learning basic digital skills early helps develop critical thinking, creativity, and problem-solving abilities. Secondly, the integration of ICT into the educational process at the early stages ensures continuity and continuity between preschool and school education. This helps children adapt more easily to the school curriculum and provides a unified methodological approach to learning.

Construction of new models for assessing the quality of IT competencies in digital education of preschool organizations is a necessary step to ensure compliance with modern

Copyright © 2024, Authors. This is an open access article under the Creative Commons CC BY license

educational standards, improve the quality of education, and effectively manage the educational process.

The practical significance of such research is in the development of effective models and methods for assessing and developing IT competencies that can be used in preschool educational organizations. These models will improve the process of monitoring and managing the educational process, reduce labor and material costs, and improve the quality of the information provided. The introduction of such systems contributes to the construction of a transparent and targeted assessment system, which enables more effective interaction between teachers, children, and their parents.

In addition, the results of such studies could be used to compile recommendations and methods aimed at individualizing the educational process. This will take into account the unique characteristics and needs of each child, thereby providing a higher level of preparation for further education and life in a digital society. Thus, the topic of developing IT competencies in children of senior preschool age is not only relevant but also extremely important for providing complete and high-quality preschool education.

2. Literature review and problem statement

Paper [1] reports the results of a study on the use of cultural heritage in education through the introduction of digital technologies. The authors showed that developing students' skills further contributes to sustainable education (SE). Drawing on findings collected through mixed methods, the paper contributes to the literature with a new conceptual model of learning that uses tangible and intangible cultural heritage and highlights the impact of digital cultural heritage as part of sustainable education. However, the authors studied methods that allow adapting cultural heritage to digital technologies and did not consider methods for individualizing the learning process as a whole.

Work [2] describes an example of the use of educational platforms in primary education. Study [3] theocratizes the practice of teachers' encounters with radical cases of digitalization. However, scalability issues are not reflected in these studies since only local experience is presented.

Paper [4] applied text mining and predictive modeling methods to a compilation of documents related to digitalization in aesthetic, artistic, and cultural education as a prototypical, loosely defined, fragmented discipline. The authors identified hot spots for further predictive modeling. However, the authors note that the use of significance ratings for specific text objects in the middle of an iterative procedure could have a weakening effect on the order of document checking.

Study [5] proposes and explores types of computational thinking, creative practices, design activities and opportunities for inclusive learning. The research of the authors is very deep but does not fully cover needs in studying the features of managing the formation of competencies.

By reviewing unique data on early childhood learning and development [6], the authors provide clues to a better understanding of the cognitive and behavioral aspects of child psychology. Although the detailed analysis methods used provided insight into students' use of computational thinking concepts and practices, they were also extremely time-consuming to complete. And the study examines the features of developing the competencies of older children.

Study [7] assessed the impact of Thrive by Five content on caregivers' knowledge, behavior, attitudes, and confidence; how content changes relationships at the family, community, and system levels; how cultural and contextual factors influence engagement and content effectiveness, and the processes that facilitate or hinder the success of adoption and dissemination. However, site-specific samples may be skewed towards those from higher socio-economic groups with greater access to digital technologies and/or from urban areas where digital infrastructure tends to be more developed.

Game-based learning, personalized education, and the use of multimedia resources open up new opportunities for interdisciplinary research, including education, psychology, computer science, and cognitive science [8]. However, the issues of assessing the formed competencies are not disclosed. An option to overcome the corresponding difficulties may be to formalize the evaluative approach to game-based learning.

Research in the field of professional development of teachers [9] reveals new requirements for the skills and competencies of preschool teachers in the digital era. The study is very useful for understanding the principles and methods of preparing future teachers in the digital era.

One of the important global trends is the development of human capital and support for the digitalization processes of kindergartens and mini-centers, the achievement of qualitatively new states in the field of education, where information culture is defined as a strategic task. The current state of preschool education and training requires a decision on the development of the educational environment. Creating high-quality digital educational content for preschool children is also a strategic and urgent task [10–13].

An example of building a model for the structure and representation of data in an information environment is described in [14, 15]. Of interest is the constructed logical model for analyzing information system data, as well as the role of decision makers. However, the study is focused on educational organizations that have 2 or more corporate information systems.

Work [16] is interesting in its approach to constructing a decision support model for assessing the quality of training, based on the use of the method of expert assessments and a criterion-based data analysis model. However, the limitations of using these approaches are the distance learning format and the impossibility of application for preschool organizations.

Work [17] discusses the development of a model for managing data and information processes, which will make it possible to determine the learning outcomes of preschoolers and adjust individual work with them. Using this model will make it possible to automatically carry out calculations, save data and generate reports for each child or group of children in an individual card. The described model can be used in the information and educational environment of preschool education organizations in order to increase the efficiency of monitoring and management of educational processes. It does not consider a model for assessing the level of development of competencies of children of senior preschool age. This paper is a logical continuation of the authors' work on managing the formation of competencies of children in preschool organizations.

Work [18] reports a study on the development of a new methodology for assessing the level of development of students' competencies based on certification results using standard tools. The advantage of this technique is the use of fuzzy typing aggregation of the results obtained when students solve various assessment tasks, which makes it possible to take into account the uncertainty and variability of the data. However, the disadvantages are the possible difficulty of introducing this procedure into practice and the need for additional training of teachers to effectively use the proposed approach.

Study [19] considers the concept of mathematical competence, substantiating the relevance of the effective formation and assessment of mathematical competencies using a fuzzy model. The advantage of the work is the development of objective criteria for determining quantitative and qualitative indicators, as well as assessing the level of all components of mathematical competence. Disadvantages are related to difficulties in the practical application of the proposed model and the need for significant resources for its implementation and integration into the educational process.

In [20], the study considers the development of a model for analyzing information obtained as a result of monitoring student competencies, based on the concepts of a fuzzy set and a linguistic variable. The advantage of this model is the ability to reduce qualitative characteristics to a single unified form and operate them on a single universal set. Disadvantages are related to the complexity of implementing the model in practice and the requirement of highly qualified specialists for its correct application.

In [21], the study addresses the problem of optimizing the level of specialist training, formulated as a multicriteria nonlinear discrete programming problem. The advantage of the proposed approach is the use of the objective function in the form of a weighted arithmetic average, which provides the necessary degree of proportionality of the assessments of individual competencies specified by their reference (target) values. Disadvantages are related to the complexity of the mathematical model and the requirement of significant computing resources to solve it.

Study [22] considers the original development of one of the soft models of fuzzy multiparameter assessment of competencies. The advantage of this work is a detailed description of the mathematical apparatus of the model, taking into account the requirements of fuzzy logic, which allows flexible and accurate assessment of competencies. Disadvantages may be the difficulty in applying the model in practice and the need for specialized knowledge to implement it.

Study [23] focuses on improving the system for assessing competencies described in the educational program of the specialty. The advantage of the work is the use of a hierarchical fuzzy model in the fuzzyTECH program, which enables high accuracy and flexibility of estimation. The adequacy of the proposed model is confirmed by statistical agreement with the results of certification of undergraduates. In addition, the model demonstrated that combining competencies in the process of writing and defending a master's thesis leads to a synergistic effect. Disadvantages are related to the difficulty of integrating the model into existing educational processes and the need to train teachers to work with the new system.

Study [24] considers the use of a fuzzy logical approach to prioritize the importance of dimensions in a model for ranking employee competencies. The advantage of this approach is the ability to accurately determine key criteria that are important to employers. The study found that critical thinking and problem solving are the top criteria expected by employers in the Vietnamese labor market. Disadvantages are the difficulty of applying the fuzzy logic approach in different contexts and the need to adapt the model to the specificity of each labor market.

Study [25] considers the problem of quantitative assessment of college students' ability to intercultural communication. The strength of the study is the development of measures of intercultural competence and the establishment of factor indicators of intercultural competence. A fuzzy comprehensive method for assessing intercultural competence was also constructed. The subjects of the study were second-year undergraduate students from various university majors, and a general assessment of intercultural communicative competence was conducted to examine the differences between different groups of students. Disadvantages are difficulties in applying the developed method in practice and the need to adapt to the specificity of various educational contexts.

In [26], a fuzzy approach to assessing competencies in school is proposed, based on the structure and features of competency cards using a 2-tuple model. The advantage of this approach is the possibility of a more accurate and objective assessment of students' competencies, taking into account their individual characteristics. It is also expected to provide guidance on the implementation of services for assessing educational competencies, which will help teachers and school administrators effectively use the developed approach in practice. Disadvantages are difficulties in implementing this approach in a school environment and the need for additional training for teachers to work with new services.

From our review of the literature [18–26], it is clear that the development and application of fuzzy logic methods for assessing and managing competencies are actively evolving in various educational contexts. There has been significant interest in the construction of mathematical and algorithmic models that allow for greater accuracy and flexibility in assessing the level of various competencies, including mathematical, IT competencies, and intercultural communication skills. These studies cover a wide range of educational levels, including higher and secondary education, and are aimed at optimizing assessment processes, as well as improving the effectiveness of educational programs. Thus, although the studies reviewed primarily focus on adult learners, they provide valuable methodological approaches and tools that can be adapted and applied in the context of early childhood education settings.

However, the emphasis in the above works is primarily on assessing the competencies of adult learners or students while the issues of developing and assessing competencies in preschool educational organizations remain less studied. This indicates the potential possibility and need to expand the application of the devised methods and approaches to the early stages of education.

The use of fuzzy logic methods in preschool educational organizations can offer new prospects for a more adaptive and individualized assessment of children's development, taking into account their unique educational needs and developmental characteristics at an early age. This approach could provide a more accurate and flexible response to the educational needs of children, contributing to the effective formation of key competencies already in preschool age.

3. The aim and objectives of the study

The purpose of our work is to build a fuzzy model for managing the formation of IT competencies, which will make it possible to assess the level of competencies of children of senior preschool age and support decision-making for the formation of the required level of both IT and general competencies.

To achieve this goal, it is necessary to solve the following tasks:

– to construct a fuzzy logic model to assess the level of development of IT competencies, allowing us to take into account uncertainty and subjectivity in the assessment;

– to build a production model for knowledge representation that provides adaptability and flexibility of the process of managing the formation of IT competencies;

– to offer recommendations for decision-making when assessing and developing competencies.

4. The study materials and methods

The object of our study is the process of managing the formation of competencies in children of senior preschool age.

The subject of the research is mathematical and algorithmic support for the information and educational environment of a preschool organization.

The main hypothesis of the study assumes that the introduction of a fuzzy model for assessing the level of development of IT competencies, in combination with a production model of knowledge representation, developed on the basis of fuzzy inference rules, will improve the efficiency of the process of managing the formation of IT competencies in children of senior preschool age.

Assumptions accepted in the work:

– the information and educational environment of a preschool organization must have flexibility and adaptability to integrate fuzzy logic methods and production models into the management and evaluation process;

– a fuzzy model and a production model of knowledge representation will provide for increased accuracy and objectivity in assessing the level of development of IT competencies, which contributes to more effective individualization and adjustment of the educational process.

The study was focused on developing and testing a fuzzy model for managing the process of developing IT competencies in preschool institutions. The research used methods of system analysis, control theory, mathematical modeling, and fuzzy logic. To implement the model, MATLAB software and Fuzzy Logic Toolbox were used, which made it possible to build a detailed simulation model of process control. Experiments to validate the model were carried out in a controlled educational environment, in which the interaction between process participants and the system was analyzed. Validation of the model included checking its ability to adequately assess and predict the level of IT competencies based on real data obtained from teachers and children, which made it possible to evaluate the effectiveness of the proposed solutions under real conditions. Research methods:

– system analysis for a comprehensive study and assessment of the processes of developing IT competencies and their impact on the educational process;

– management theory to determine the best management strategies in the context of developing IT competencies;

– mathematical modeling and fuzzy logic for the development and testing of a fuzzy model for assessing the level of development of IT competencies;

– expert methods and methods for formalizing the representation of knowledge to build a production model based on the rules of fuzzy inference.

5. Research results – construction of a fuzzy model for managing the process of forming IT competencies

5. 1. Building a fuzzy logic model to assess the level of development of IT competencies

The main hypothesis of the study assumes the introduction of a fuzzy model for assessing the level of development of IT competencies, in combination with a production model of knowledge representation. This model was built on the basis of fuzzy inference rules and could improve the efficiency of the process of managing the formation of IT competencies in children of senior preschool age.

In the republican education system, an approach corresponding to the Bologna practice [27] is widespread, based on assessing the maturity of competencies by introducing levels and criteria for this maturity. One of the main methods for implementing this approach is the decomposition of competencies into indicators of achievement of competencies. This, in turn, is a set of characteristics that clarify and reveal the formulation of competence in the form of learning outcomes and/or specific actions performed by the graduate. After mastering these competencies, which, according to them, should be measured using the means available in the educational process [28].

In world practice, so-called descriptors are used to measure indicators of achievement of competencies, which in general can be defined as qualitative assessment criteria that describe the level of manifestation of the indicator of achievement of competencies (low, medium, high). This provides grounds for determining the degree of development of the student's competencies.

The most widely used are the Dublin descriptors, developed with the aim of systematizing level descriptors in different countries, in the form of characteristics of knowledge, skills, and abilities that a graduate of an educational organization should have [29].

Most authors and developers of educational programs identify descriptors with learning outcomes. At the same time, Bloom's taxonomy is most often used to formulate descriptors, reflecting learning outcomes through knowledge, skills, and abilities.

Fig. 1 shows a diagram of the description and formation of competencies.

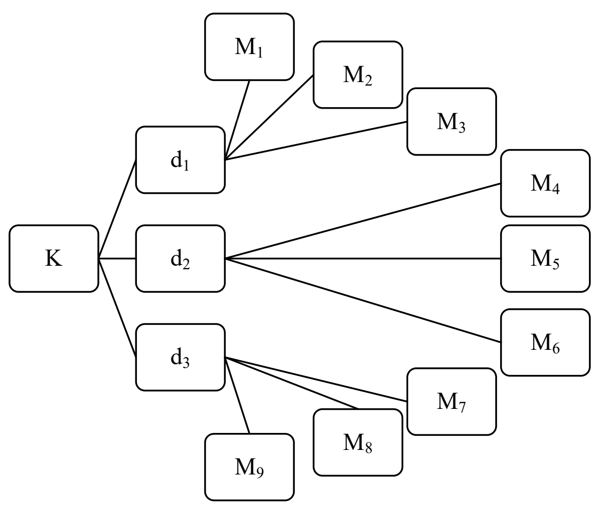

Fig. 1. Descriptive description of competencies: K – competency; d_1 – knowledge tested in children; d_2 – skills tested in children; d_3 – skills (proficiency) tested in children; M_1 – knows; M_2 – answers with a hint; M_3 – doesn't know; M_4 – can do it independently; M_5 – can with support; M_6 – can't; M_7 – automatic; M_8 – basic; M_9 – not formed

The descriptor describes some activity that the subject exhibits in relation to control objects determined by the learning results. Consequently, it is advisable to formulate descriptors taking into account the formulations of the assessed learning outcomes, by which we mean the traditional elementary ones: know, be able to, master. When making this connection when developing assessment tools for educational activities, the teacher educator (expert), as a rule, experiences some uncertainty in classifying certain tasks as competencies. Repeated monitoring and a large number of subjects in educational activities do not always allow this to be carried out unambiguously. Thus, fuzzy uncertainty inevitably arises here, the accounting and processing of which turns out to be a necessary stage in solving the problem of assessing the maturity of competencies.

The use of fuzzy logic to manage the process of developing competencies can be justified by the following factors and advantages:

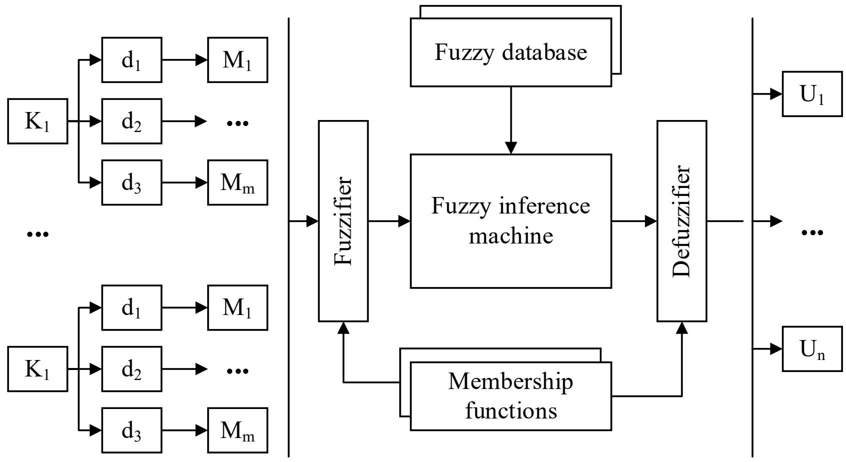

Fig. 2. Management model for the formation of IT competencies based on fuzzy inference: K_1 – formulated competence, d_i – competence descriptors, M_i – expert assessments of tasks, U – assessment of the level of competence development

1. Taking into account uncertainty: the formation of competencies is often associated with many uncertain factors, such as the level of knowledge and skills of students, the learning context, individual characteristics, etc. Fuzzy logic makes it possible to effectively take into account this uncertainty and work with fuzzy and unstructured information.

2. Linguistic assessments: competencies are often characterized by linguistic terms such as «good», «average», «advanced», etc. Fuzzy logic allows such fuzzy and linguistic assessments to be dealt with, making it suitable for describing competencies.

3. Multi-criteria analysis: assessment of competencies usually includes consideration of several criteria, such as knowledge, skills, level of adaptation to new situations, etc. Fuzzy logic allows taking into account multiple criteria and their interaction in the process of developing competencies.

4. Adaptability and flexibility: fuzzy control systems are able to adapt to changing conditions and context. This is important in the area of competency development, where requirements and expectations may change over time.

5. Expert knowledge: competency assessors often use unclear terms and opinions. Fuzzy logic makes it possible to take into account expert knowledge and preferences in the competency management process.

6. Managing fuzzy goals: fuzzy logic can be used to manage fuzzy goals for competency building. This allows for more flexible adaptation of training to the individual needs of students.

7. Modeling complex relationships: competencies may depend on complex relationships between various factors. Fuzzy logic makes it possible to model and take into account such relationships.

Taking into account all the above circumstances, it is necessary to construct a model for assessing the formation of IT competencies under conditions of fuzzy uncertainty of assessment criteria.

Current research [30] has shown that fuzzy uncertainty, including in the field of education, can be taken into account and effectively processed through the use of mathematical methods of fuzzy logic.

The production model for managing the process of forming IT competencies is shown in Fig. 2.

The task of fuzzy inference [31] in modeling the process of managing the formation of competencies is to use fuzzy logic for decision making and forecasting in the context of the formation of IT competencies.

The key stages of the fuzzy inference modeling task in managing the process of developing competencies include: linguistic variables: in the context of developing IT competencies, linguistic variables include the following variables: let T_1 be a task that makes it possible to form the level of proficiency in some competency K_1. Let us assume that the formation of competence K_1 consists of descriptors d_1, d_2 and d_3 characterizing the complexity of the task: respectively, representing Knowledge, Abilities and Skills (proficiency). For example, IT competency K=«use standard shapes to create an image» depends on the components d_1=«knowledge of standard shapes to create an image», d_{12}=«ability to use standard shapes» and d_{13}=«skill to use standard shapes to create images». Variable M – expert assessments of tasks. U – assessment of the level of competence development, represented according to formula (1):

$$M \xrightarrow{f} U;$$

$$M=\{M_m\};$$

$$U=\{U_1, U_2, U_3\}. \qquad (1)$$

This transformation transforms the set M into the set U, where i is the competency number.

In this problem, the input parameters are taken into account not in an exact measurement but in a certain range of values with corresponding linguistic terms. Table 1 defines the input parameters (variables d_1, d_2 and d_3) and output parameters (variable U) as follows.

Membership functions: for all input and output variables K and U, a Gaussian membership function was chosen during the modeling process. It is well suited for approximating complex distribution shapes when the data is smoother, used to smoothly model data distributions and account for large degrees of uncertainty. Often used in control and modeling problems in which accuracy and smoothness are needed. The general form of the Gaussian type of membership function is represented in formula (2):

$$MF = \exp\left[-\left(\frac{x-c}{\varphi}\right)^2\right], \quad (2)$$

where the parameter c denotes the center of the fuzzy set, and φ is responsible for the functions.

Table 1

Linguistic terms of input and output variables

Variable	Term-set
d_1 – Knowledge	{doesn't know; answers with a hint; knows}
d_2 – Capabilities	{can't; can with support; can do it independently}
d_3 – Skills	{not formed; basic; automatism}
U – Level (of competence formation)	{low; average; high}

The membership function for variables may take the following form:

[Input1]
Name='Knowledge'
Range=[0 1]
NumMFs=3
MF1='doesn't know':'gaussmf',[0.2123 4.627e-18]
MF2='answers with a hint':'gaussmf',[0.2123 0.5]
MF3='knows ':'gaussmf',[0.2123 1]
[Input2]
Name='Capabilities'
Range=[0 1]
NumMFs=3
MF1='can't:'gaussmf',[0.2122 9.253e-18]
MF2='can with support':'gaussmf',[0.2121 0.5]
MF3=' can do it independently ':'gaussmf',[0.2122 1]
[Input3]
Name='Skills'
Range=[0 1]
NumMFs=3
MF1='not formed':'gaussmf',[0.2123 1.388e-17]
MF2='basic':'gaussmf',[0.212 0.5007]
MF3='automatism':'gaussmf',[0.2123 0.9947]
[Output1]
Name='Level'
Range=[0 1]
NumMFs=3
MF1='low':'gaussmf',[0.07077 0.1667]
MF2='average':'gaussmf',[0.07077 0.5]
MF3='high':'gaussmf',[0.07077 0.8333].

5. 2. Construction of a production model for knowledge representation that enables the process of managing the formation of IT competencies

Formulation of fuzzy rules: experts or preschool teachers can create rules of the form «if (level of knowledge) Low and (skills) Average, then (competencies) Insufficient». These rules describe what conclusions to draw based on data and expert knowledge.

In a Mamdani-type model [32], the relationship between inputs $K=(d_1, d_2, d_3)$ and output U is determined by a fuzzy knowledge base using the operations ∪ (OR) and ∩ (AND) and in general it takes the following form:

$$\text{IF}(d_1 \text{ is } a_1^j) \text{ and } (d_2 \text{ is } a_2^j) \text{ and } (d_3 \text{ is } a_3^j) \text{ then } U \text{ is } b_n^j.$$

For the aggregation of fuzzy rules, the following implementations are most often used: for the OR operation – finding the maximum, for the AND operation – finding the minimum.

At the initial stage of modeling, basic rules were formulated using the AND operation. The generation of rules is shown in Fig. 3.

The next stage of the design was the development of all possible cases of variants of input variables involving all terms with the exception of combinations that are meaningless and do not affect the resulting surface of the fuzzy model. Aggregation of rules was carried out using the AND operation – finding the minimum is presented.

Table 2 gives the Rule Base for the production model.

The software implementation of these rules using the Fuzzy Logic Toolbox package of the MATLAB software is shown in Fig. 4.

Defuzzification: After aggregating fuzzy outputs, they are converted into concrete numerical values or linguistic terms that can be used for decision making. The clear output value corresponding to the input vector is determined as a result of defuzzification of the fuzzy set.

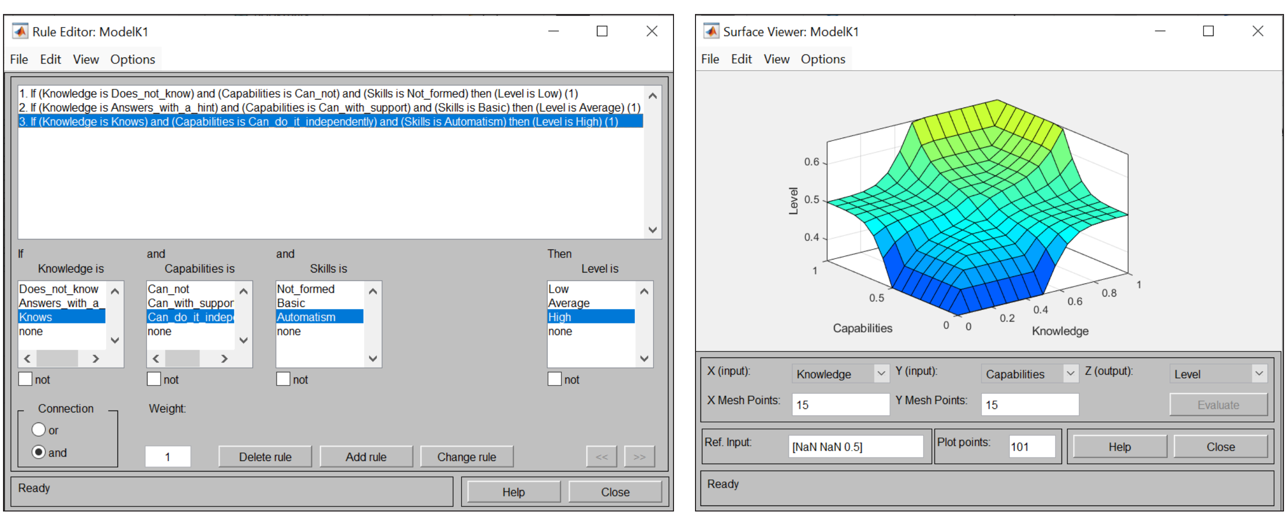

Fig. 3. Basic rules of the production model

Table 2

Production model rule base

No. of entry	Knowledge	Capabilities	Skills	Level
1	Does not know	Can not	Not formed	Low
2	Does not know	Can not	Basic	Low
3	Does not know	Can not	Automatism	–
4	Does not know	Can with support	Not formed	Low
5	Does not know	Can with support	Basic	Low
6	Does not know	Can with support	Automatism	Low
7	Does not know	Can do it independently	Not formed	Low
8	Does not know	Can do it independently	Basic	Low
9	Does not know	Can do it independently	Automatism	Average
10	Answers with a hint	Can not	Not formed	Low
11	Answers with a hint	Can not	Basic	Low
12	Answers with a hint	Can not	Automatism	Average
13	Answers with a hint	Can with support	Not formed	Low
14	Answers with a hint	Can with support	Basic	Average
15	Answers with a hint	Can with support	Automatism	Average
16	Answers with a hint	Can do it independently	Not formed	Average
17	Answers with a hint	Can do it independently	Basic	Average
18	Answers with a hint	Can do it independently	Automatism	High
19	Knows	Can not	Not formed	Low
20	Knows	Can not	Basic	Average
21	Knows	Can not	Automatism	Average
22	Knows	Can with support	Not formed	Average
23	Knows	Can with support	Basic	High
24	Knows	Can with support	Automatism	High
25	Knows	Can do it independently	Not formed	High
26	Knows	Can do it independently	Basic	High
27	Knows	Can do it independently	Automatism	High

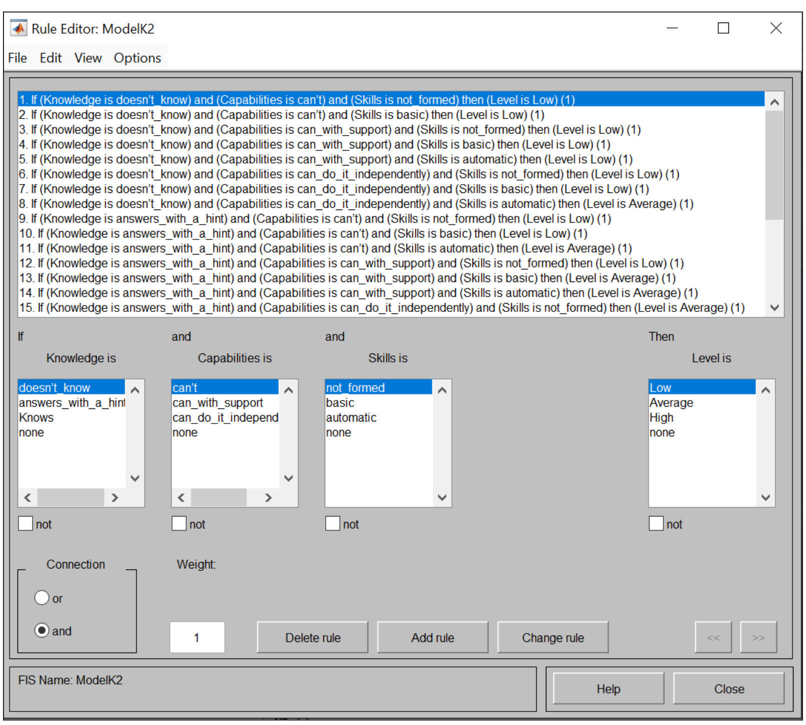

Fig. 4. Production model rule set

The study uses defuzzification using the center of gravity method, represented by formula (3):

$$y=\frac{\int_{\min}^{\max} y\mu_r(y)\mathrm{d}y}{\int_{\min}^{\max}\mu_r(y)\mathrm{d}y}, \qquad (3)$$

where $\mu_r(y)$ is the resulting membership function obtained by summing the partial truncated membership functions $\mu_j^r(y)$, obtained when the j-th rule was triggered [33].

Performing fuzzy logical inference with the values of the input variable $d_1=0.652$, $d_2=0.676$, $d_3=0.77$, then the result of calculating the model is $u=0.624$ in accordance with Fig. 5.

The surface of the fuzzy model for the rule base in the context of Knowledge and Skills is shown in accordance with Fig. 6.

The surface of the fuzzy model for the rule base in the Skills and Knowledge section is shown in Fig. 7.

Understanding the surface in question allows one to determine which combinations of knowledge and skills most effectively contribute to the development of competencies.

Fig. 5. Example of fuzzy inference rules implementation

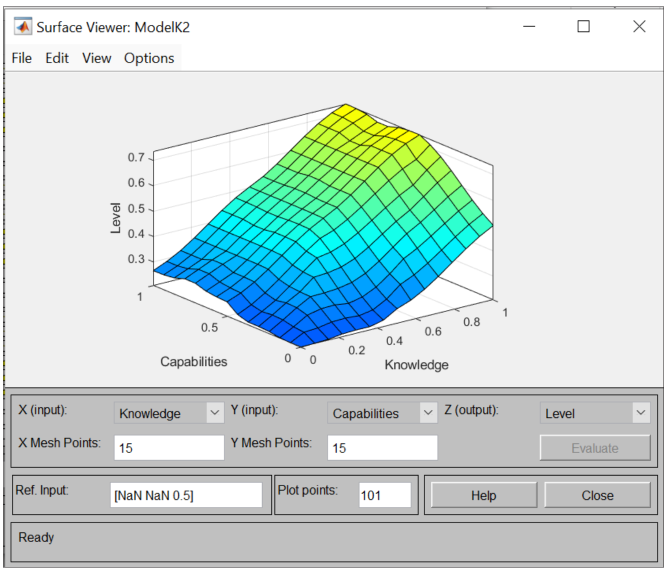

Fig. 6. Surface of a fuzzy model for a rule base in the context of Knowledge and Skills

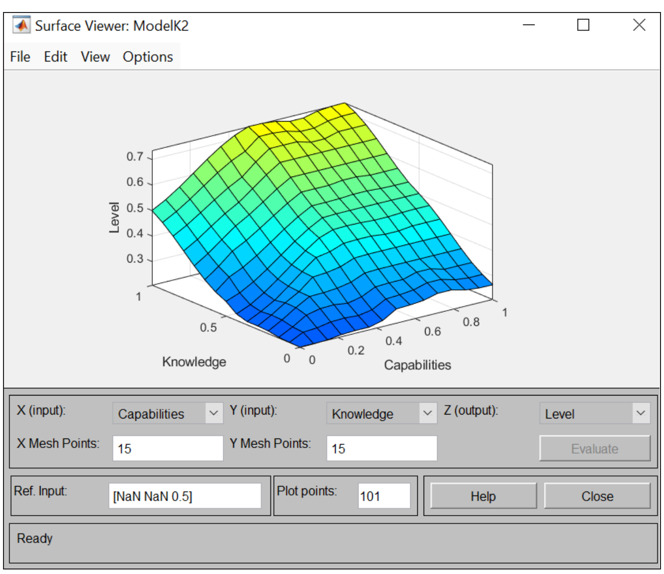

Fig. 7. Surface of a fuzzy model for a rule base in the context of Skills and Knowledge

For example, if the surface shows that at low levels of knowledge, increasing skills does not lead to significant improvements in competencies, this may indicate that without basic knowledge, practical skills are ineffective. This information can be used to develop training programs that emphasize the balance between knowledge and skills. It may be advisable to adjust curricula to focus on building critical knowledge first before moving on to practical skills.

5. 3. Recommendations for making decisions when assessing and developing competencies

Decision making: Based on defuzzied conclusions and expert knowledge, decisions can be made regarding the competency development management process. The interpretation through the developed model is as follows:

1. High level of development of digital competencies in children 5–6 years of age. These levels are as follows:

– knowledge: memory of facts and information;

– skills (comprehension, application): understanding the meaning and interpreting information. Applying knowledge and understanding to new situations;

– skills (analysis, synthesis, and evaluation):

a) decomposing information into components and identifying relationships;

b) creating new information or ideas from existing ones;

c) assessing, comparing, and making decisions based on information;

d) if the child can evaluate and compare different digital resources (for example, games or applications) in terms of their usefulness, quality, or developmental potential;

e) if the child can make decisions about which digital tool or resource to use in a particular situation and explain their choice;

f) if the child can critically evaluate information received from digital sources and distinguish between reliable and unreliable sources;

g) if the child is able to use digital technologies to solve problems and problems, and to create creative content such as drawings, cartoons, or stories.

Assessing digital competencies in children requires special attention to their development and abilities. The assessment approach should be tailored to the age and skill level of each individual child.

2. The average level of achievement of digital competencies by a preschooler will depend on the specific goals of the task and organized activity, including criteria such as:

– knowledge: at this level, a preschooler can demonstrate knowledge of basic concepts and terms in the field of digital competencies. For example, he can explain what a computer, mouse, keyboard, screen, etc. are.

– skill (understanding, application):

a) understanding: Here the child can demonstrate an understanding of how some digital devices and tools work. For example, s/he can explain what you need to do to turn on the computer, how the touch screen works, and what its function is.

b) application: this level involves the use of digital competencies in practical situations. For example, a child can demonstrate that they can turn on a computer, open a game or application, and begin using it.

The average level will depend on how successfully the child completed the tasks on each of the knowledge, skills, and abilities presented above. The specific criteria for establishing the average score will depend on the context and purpose of the assessment and can be developed by the educator according to the monitoring conditions.

3. In terms of developing digital competencies, the following assessment criteria correspond to a low level:

– knowledge:

a) if the child cannot name or identify basic digital devices, such as a computer, tablet, smartphone;

b) if the child does not know the names or functions of the main interface elements (for example, buttons, screen, mouse).

– skills (understanding, application):

a) understanding:

1) if the child cannot explain how to use simple programs or applications, such as drawing or playing games on the computer;

2) if the child cannot explain basic digital security concepts, such as the need to use passwords or not disclose personal information;

b) application:

1) if the child cannot use his digital skills to solve simple problems, such as creating a drawing on a computer or searching for information on the Internet;

2) if the child cannot use simple programs for play or entertainment.

6. Discussion of results of the study on building a fuzzy model for managing the process of forming IT competencies

Our developed fuzzy logic model allows us to take into account uncertainty and subjectivity in assessment. This is due to the use of linguistic variables and membership functions that reflect the variability of scores, as shown in Table 1 and formula (2). For example, the knowledge variable (d_1) has the terms «low», «medium», «high», which allows us to more accurately account for differences in assessments. The use of a Gaussian membership function (2) provides a smooth modeling of the data distribution, which better accounts for the degree of uncertainty. Fig. 1 shows how different levels of knowledge, skills (d_1, d_2, d_3) affect the overall assessment of the level of competence (U). Unlike traditional methods, which can use rigid and limited assessment criteria, the proposed model allows taking into account many factors, such as knowledge, skills, and abilities. This is possible thanks to the use of fuzzy logic, which makes the model more flexible and adaptive. In addition, the presented model allows working with linguistic assessments such as «good», «average», «advanced», which makes it suitable for describing competencies. Unlike studies that used strict criteria (for example, fixed scores), the proposed model provides a more accurate assessment by taking into account expert knowledge and subjective opinions. The fuzzy logic model solves the problem of uncertainty and subjectivity of assessment. It allows for individual differences and learning context to be taken into account, making assessment more personalized and accurate. This is explained by the use of membership functions and fuzzy logic rules, which make it possible to achieve higher levels of accuracy and reliability of the assessment (Table 3).

The solution to the problem of developing a production model for knowledge representation is based on «if-then» rules and enables adaptability and flexibility of the process of managing the formation of IT competencies. This allows the system to dynamically respond to changes in the educational environment and the individual needs of students (Fig. 2). Unlike static models, the production model allows rules to be dynamically changed and updated depending on current conditions and context. In the proposed model, production rules provide high adaptability and flexibility, which is confirmed by the data in Fig. 4. The production model solves the problem of insufficient adaptability of the educational process. It allows dynamic adaptation to children's individual needs and changing conditions, which significantly increases the effectiveness of the learning process.

Offering recommendations for decision-making when assessing and developing competencies is based on modeling and analysis of data obtained using the developed models. This enables high validity and accuracy of recommendations (Table 2 and formula (3)). Unlike traditional recommendations, which may be based on outdated data and fixed techniques, the proposed recommendations are dynamically updated and based on fuzzy logic. This makes it possible to receive more accurate and relevant recommendations, which is confirmed in Fig. 6, 7. Recommendations for decision making solve the problem of insufficient validity and accuracy of management decisions. They are based on dynamic analysis and modeling, which makes it possible to make more informed and accurate decisions.

Our model makes it possible to reflect the process of developing competencies through an individual map of the information and educational environment and provides assessment of three-stage monitoring when managing the educational process of a preschool organization. An individual card as a data management tool for the information and educational environment of a preschool organization makes it possible to determine the results of the educational process and adjust individual work with children 5–6 years of age.

To monitor children with special education needs, it is recommended to adapt the criteria in accordance with the Standard, in which standard, educational, special, individual/adapted educational programs that meet the educational needs of the child are used when raising and teaching children with special needs and disabilities. Monitoring in different age groups is carried out in accordance with the age of the children.

Thus, it is possible to effectively organize the educational process with the whole group and individually with the child in order to determine the children's assimilation of the content of the program. Acquisition of skills using one's own knowledge, as well as the level of achievement of the expected result by children and the teacher and plan upcoming work according to the child's individual development map.

Carrying out monitoring in accordance with the indicators of each criterion allows it to be carried out realistically. It helps to see the full result of mastering the content of the curriculum of the entire group and achieving its goal. Their full development and disclosure of potential on the basis of universal and national values, taking into account the interests, characteristics and needs of each child.

Using monitoring to assess IT competencies in preschool institutions allows one not only to assess the current level of knowledge and skills of children but also to track the dynamics of their development. The monitoring results demonstrate the effectiveness of the introduction of multimedia technologies and specialized educational programs, confirming that children are becoming more competent in using digital resources.

The main advantage of this study is the systematic approach to assessing and developing IT competencies in children using fuzzy logic to adapt curriculum to the individual needs of the child. This distinguishes the study from similar approaches, in which such individualization may not be as pronounced.

Despite its successes, the study has a number of limitations. For example, the results depend on the quality and completeness of the monitoring, as well as on the objectivity of expert assessments. In addition, the influence of socio-economic factors and the home educational environment on the monitoring results was not considered in this work.

One limitation is the limited sample size, which may affect the generalizability of the results. Also, the use of fuzzy logic requires a more in-depth analysis of the influence of the choice of membership functions and defuzzification methods on the evaluation results.

Further development of the study could include expanding the experimental framework, including additional variables in the analysis, such as social and cultural contexts. An important direction is also the development and testing of more complex fuzzy logic models that can account for diverse and often conflicting data on competency development.

Our developed fuzzy logic model and production model of knowledge represent significant progress in assessing and developing IT competencies in preschool children. Their advantages are in taking into account uncertainty and subjectivity, flexibility in managing the educational process, and improving the quality of education through individualization of the educational process. However, implementation of these models may prove challenging due to teacher training requirements, difficulty adapting to specific contexts, and the need for additional resources. However, these models promise significant contributions to advancing education and preparing children for the digital age.

7. Conclusions

1. Our constructed fuzzy logic model for assessing the level of development of IT competencies demonstrates significant potential in taking into account the uncertainty and subjectivity characteristic of the process of assessing the competencies of preschool children. The use of fuzzy logic makes it possible to work with linguistic variables and multi-criteria analysis, which makes the assessment more flexible and adaptive to the individual characteristics of children. Expert assessments and linguistic terms are introduced into the modeling process, simplifying the interpretation of the results, and making them more understandable for teachers and parents. Gaussian membership function and center of gravity defuzzification contribute to the accuracy of the conclusions and their practical relevance.

2. The production model of knowledge representation, which provides for adaptability and flexibility in managing the formation of IT competencies, is a significant step towards creating a dynamic and reactive educational environment. The formulation of fuzzy rules allows teachers and developers of educational content to create conditions for individualizing the educational process, taking into account the diversity of levels of training and preferences of students. The model promotes closer integration of expert knowledge into the educational process, increasing its quality and efficiency. Software implementation of the model in the MATLAB environment and subsequent defuzzification of the conclusions serve as a powerful tool for optimizing educational strategies.

3. The proposed recommendations for making decisions based on the results of assessment and development of competencies could significantly increase the efficiency of the educational process. Interpretation of defuzzified findings, combined with expert knowledge, provides the basis for the development of individual and group educational plans. This promotes a more conscious approach to children's learning and development, allowing for an integrated approach to the formation and development of key competencies. The introduction of these recommendations into the practice of preschool education could significantly improve the quality of children's preparation for school, as well as support their intellectual and creative development.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

Funding

This research is funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP15473432).

Data availability

The manuscript has associated data in the data warehouse.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Orphanidou, Y., Efthymiou, L., Panayiotou, G. (2024). Cultural Heritage for Sustainable Education Amidst Digitalisation. Sustainability, 16 (4), 1540. https://doi.org/10.3390/su16041540
2. Mingot, S. G., Marín, V. I. (2024). Digital educational platforms in primary education: the case of Catalonia. Technology, Pedagogy and Education, 1–19. https://doi.org/10.1080/1475939x.2024.2337346
3. Willermark, S., Gellerstedt, M. (2022). Facing Radical Digitalization: Capturing Teachers' Transition to Virtual Classrooms Through Ideal Type Experiences. Journal of Educational Computing Research, 60 (6), 1351–1372. https://doi.org/10.1177/07356331211069424
4. Christ, A., Penthin, M., Kröner, S. (2019). Big Data and Digital Aesthetic, Arts, and Cultural Education: Hot Spots of Current Quantitative Research. Social Science Computer Review, 39 (5), 821–843. https://doi.org/10.1177/0894439319888455

5. Richard, G. T., Giri, S. (2019). Digital and Physical Fabrication as Multimodal Learning. ACM Transactions on Computing Education, 19 (3), 1–35. https://doi.org/10.1145/3243138
6. Falloon, G. (2024). Advancing young students' computational thinking: An investigation of structured curriculum in early years primary schooling. Computers & Education, 216, 105045. https://doi.org/10.1016/j.compedu.2024.105045
7. LaMonica, H. M., Song, Y. J. C., Loblay, V., Ekambareshwar, M., Naderbagi, A., Zahed, I. U. M. et al. (2024). Promoting social, emotional, and cognitive development in early childhood: A protocol for early valuation of a culturally adapted digital tool for supporting optimal childrearing practices. DIGITAL HEALTH, 10. https://doi.org/10.1177/20552076241242559
8. Boyes, R., Pickett, W., Janssen, I., Swanlund, D., Schuurman, N., Masse, L. et al. (2023). Physical environment features that predict outdoor active play can be measured using Google Street View images. International Journal of Health Geographics, 22 (1). https://doi.org/10.1186/s12942-023-00346-3
9. Ortiz-de-Villate, C., Gil-Flores, J., Rodríguez-Santero, J. (2023). Variables asociadas al uso de pantallas al término de la primera infancia. Pixel-Bit, Revista de Medios y Educación, 66, 113–136. https://doi.org/10.12795/pixelbit.96225
10. Digital Kazakhstan. Available at: https://egov.kz/cms/ru/digital-kazakhstan
11. Zakon Respubliki Kazahstan ot 27 iyulya 2007 goda No. 319-III «Ob obrazovanii» (s izmeneniyami i dopolneniyami po sostoyaniyu na 01.01.2024 g.). Available at: https://online.zakon.kz/Document/?doc_id=30118747&pos=0;400#pos=0;400
12. Poslanie prezidenta RK: chto skazal glava strany o razvitii kreativnoy industrii, II, tsifrovizatsii i IT. Available at: https://tribune.kz/poslanie-prezidenta-rk-chto-skazal-glava-strany-o-razvitii-kreativnoj-industrii-it-ii-i-tsifrovizatsii/
13. Postanovlenie Pravitel'stva Respubliki Kazahstan ot 28 marta 2023 goda No. 249. Kontseptsiya razvitiya doshkol'nogo, srednego, tehnicheskogo i professional'nogo obrazovaniya Respubliki Kazahstan na 2023 – 2029 gody. Available at: https://www.gov.kz/memleket/entities/edu/documents/details/451747?lang
14. Kolyeva, N., Kopnova, O., Shaporeva, A. (2021). Adaptation Information and analytical system adaptation in the contour of the corporate system of the university. E3S Web of Conferences, 270, 01037. https://doi.org/10.1051/e3sconf/202127001037
15. Kopnova, O., Shaporeva, A., Iklassova, K., Kushumbayev, A., Tadzhigitov, A., Aitymova, A. (2022). Building an information analysis system within a corporate information system for combining and structuring organization data (on the example of a university). Eastern-European Journal of Enterprise Technologies, 6 (2 (120)), 20–29. https://doi.org/10.15587/1729-4061.2022.267893
16. Shaporeva, A., Kopnova, O., Shmigirilova, I., Kukharenko, Y., Aitymova, A. (2022). Development of comprehensive decision support tools in distance learning quality management processes. Eastern-European Journal of Enterprise Technologies, 4 (3 (118)), 43–50. https://doi.org/10.15587/1729-4061.2022.263285
17. Aitymova, A., Iklassova, K., Abildinova, G., Shaporeva, A., Kopnova, O., Kushumbayev, A. et al. (2023). Development of a model of information process management in the information and educational environment of preschool education organizations. Eastern-European Journal of Enterprise Technologies, 2 (3 (122)), 95–105. https://doi.org/10.15587/1729-4061.2023.276253
18. Kramarov, S. O., Kadomtsev, M. I., Sakharova, L. V., Bocharov, A. A. (2023). Mathematical modeling of the competency-based approach in education based on the theory of fuzzy sets. Informatics and Education, 37 (5), 76–86. https://doi.org/10.32517/0234-0453-2022-37-5-76-86
19. Pankina, S. I., Lyutikova, M. N. (2023). A fuzzy model for assessing mathematical competences of university students. SHS Web of Conferences, 164, 00064. https://doi.org/10.1051/shsconf/202316400064
20. Poleshchuk, O. M. (2022). Fuzzy analysis of student competence monitoring. Science. Research. Practice (Nauka. Issledovaniya. Praktika): Sbornik Statey Mezhdunarodnoy Nauchnoy Konferentsii (Sankt-Peterburg, Oktyabr' 2022). https://doi.org/10.37539/221026.2022.70.10.006
21. Gerasimov, I. V., Ankoudinov, I. G. (2021). Evaluation of the Fuzzy Cognitive Model of Professional Competences. 2021 XXIV International Conference on Soft Computing and Measurements (SCM). https://doi.org/10.1109/scm52931.2021.9507183
22. Dashko, Y., Vitchenko, O., Kadomtsev, M. (2020). Soft models of competence assessment in professional education. E3S Web of Conferences, 210, 18011. https://doi.org/10.1051/e3sconf/202021018011
23. Hu, Z., Koroliuk, Y. (2020). A Hierarchical Fuzzy Model for Assessing Student's Competency. Advances in Artificial Systems for Medicine and Education III, 380–393. https://doi.org/10.1007/978-3-030-39162-1_35
24. Hoang Thuy To Nguyen, Q. L., Van Nguyen, P., Thanh Nguyen, P., Bich Huynh, V. D. (2018). Using Fuzzy Logic to Develop Employees' Competency Ranking Model. The Journal of Social Sciences Research, Special Issue 5, 606–609. https://doi.org/10.32861/jssr.spi5.606.609
25. Liu, M. (2024). A Study on the Enhancement of English Proficiency of Contemporary College Students by Intercultural Communication in the Background of the Internet. Applied Mathematics and Nonlinear Sciences, 9 (1). https://doi.org/10.2478/amns-2024-0061
26. Duran, D. F., Chanchí, G. E., Arciniegas, J. L. (2017). A Fuzzy Approach for Assessing Educational Competencies Based on Competency Maps. Advances in Computing, 372–386. https://doi.org/10.1007/978-3-319-66562-7_27
27. Bolonskiy protsess v Kazahstane. Available at: https://iqaa.kz/vysshee-i-poslevuzovskoe-obrazovanie/bolonskij-protsess/bolonskij-protsess-v-kazakhstane

28. Metodicheskie rekomendatsii dlya provedeniya monitoringa po usvoeniyu soderzhaniya tipovoy uchebnoy programmy doshkol'nogo vospitaniya i obucheniya (2023). Astana. Available at: http://baldauren.aqmoedu.kz/content/mektepke-deyng-trbie-menoytudy-lglk-ou-badarlamasy-mazmnyn-megeru-boy
29. Instruktivno-metodicheskoe pis'mo «Ob osobennostyah uchebno-vospitatel'nogo protsessa v organizatsiyah srednego obrazovaniya Respubliki Kazahstan v 2022-2023 uchebnom godu». Available at: https://uba.edu.kz/storage/app/media/IMP/instruktivno-metodicheskoe-pismo-ob-osobennostyakh-uchebno-vospitatelnogo-protsessa-v-organizatsiyakh-srednego-obrazovaniya-rk-v-2022-2023-uchebnom-23122022godu.pdf
30. Grigor'eva, D. R., Gareeva, G. A., Basyrov, R. R. (2018). Osnovy nechetkoy logiki. Naberezhnye Chelny: Izd-vo NCHI KFU, 42.
31. Pegat, A. (2013). Nechetkoe modelirovanie i upravlenie. Moscow: BINOM. Laboratoriya znaniy, 798.
32. Mamdani, E. H., Assilian, S. (1975). An experiment in linguistic synthesis with a fuzzy logic controller. International Journal of Man-Machine Studies, 7 (1), 1–13. https://doi.org/10.1016/s0020-7373(75)80002-2
33. Kudinov, Yu. I., Kelina, A. Yu. (2012). Metody sinteza i nastroyki nechetkih PID regulyatorov Mamdani. Informatsionnye tehnologii.