Formalization of the Pedagogical Model by the Language of Predicate Logic

M V Sleptsova[1,a*], N V Sokolova[1,b], L A Shamanina[1,c], I A Gubanova[1,d]

[1] Voronezh State Pedagogical University, 86 Lenin str., Voronezh 394043 Russia

[a]*79304014250@yandex.ru, [b]nsokolova@vspu.ac.ru, [c]dushnewa@yandex.ru, [d]irischka20@mail.ru

*Corresponding author

Keywords: e-learning, predicate logic, pedagogical models, pedagogical technologies, formalization of the model

Abstract: The article is devoted to the urgent pedagogical problem of creating formalized pedagogical models in the transition from “traditional” forms of organization of the educational process to E-learning. The language of predicate logic is chosen as the language used to formalize the description of the educational process, the educational goal, and the pedagogical models used. The questions of the relationship between the “traditional” and “formalized” description of the educational process are considered. In particular, constants and variables are defined; term sets of linguistic and fuzzy variables are formed; their relationship with quantitative and qualitative scales is established. The main educational goal is considered as a set of the second level with respect to membership functions of the corresponding variables. Key features of the application and limitations of the proposed method are identified. More than that, the authors provide directions for further research, including goals and objectives. They also comprehensively assess the possibility and expediency of using the language of predicate logic to formalize the description of the pedagogical process in E-learning.

1. Introduction

The transition from traditional forms of organization of the educational process in educational organizations of various levels to electronic education (E-learning) is a natural evolutionary process of the development of the educational system in our country and in the world. However, the scientific research on the pedagogical conditions of the E-learning organization, the possibilities and applicability in E-learning of the well-known and previously well-proven pedagogical technologies, techniques, methods, and pedagogical models has been carried out quite rarely and fragmentarily. This state of affairs is due to the fact that, in most cases, the well-known pedagogical models and pedagogical technologies implemented on their basis are described by means of the natural human language and do not have a formalized form of presentation. But natural human language contains too many "fuzzy" components and cannot be implemented by computer technology. Accordingly, there is no way to create a mathematical model suitable for its implementation by means of computer technology.

However, in contemporary science, education, namely e-learning, is seen as a fundamental process of “knowledge engineering.” Fundamentally different representation languages, software environments and platforms, models and mathematical methods are developed for it. In terms of the organization of the educational process, the language of predicate logic is of most interest among them. Using the language of predicate logic allows us to move from the description of pedagogical models and technologies by means of the natural human language to a formalized form that preserves the basic ideas, techniques, and methods of achieving the set educational goal that underlie pedagogical technology. At the same time, a formalized pedagogical model is easily transformed into a mathematical model implemented by computer technology. This approach allows you to successfully apply in E-learning the main achievements of educational science, to ensure the successful adaptation of pedagogy to a new technological basis, to ensure the availability of education and its adequacy in the new conditions.

The aim of our study is to develop theoretical provisions for formalizing pedagogical models using the language of predicate logic and practical verification of the results against the simulated process.

2. Materials and Methods

The study of the possibility of formalizing pedagogical models in education was carried out at the Voronezh State Pedagogical University using the case of the main educational program of the training direction “Pedagogical Education” of the “Technology” profile (Bachelor of Education).

The main educational program of the training direction “Pedagogical Education” of the “Technology” profile contains a linguistic description by the structures of the natural human language of the following components: main educational goal and sub goal system; systems for assessing the level of achievement of students of primary and intermediate educational goals; the sequence of achievement of basic and intermediate educational goals by a student. In our case, the purpose of education is to obtain a competent specialist, i.e., a specialist with a high level of competency development [1; 2].

We consider competence as an integrated characteristic that includes cognitive (knowledge), operational-technological (activity), motivational (emotional), ethical, social, and behavioral components (competencies) [3; 4]. In our case, the educational process is built as a sequence of learning situations (“playing”). Such situations are those forms that subsequently developed by a student to the target level cognitive, activity, motivational, ethical, social, and behavioral competencies. Each of the skills can be detailed through the “basic qualities” of the respective competencies, which, in turn, can be measured on a quantitative, qualitative, or relative scale. It is clear that in the ideal case, the basic qualities and relevant competencies should be maximally formed and developed by a student who has completed training in the main educational program of the training direction “Pedagogical Education” of the “Technology” profile. Accordingly, the main educational goal is the set of quantitative values of the basic qualities of competencies, the maximum possible for the given conditions for obtaining an education. Then the description of the leading educational goal by the predicate logic language forms will look as follows [5; 6].

Let the set X= $\{x_1, \ldots x_p\}$ be the set of basic qualities of a competent specialist that a student should have at the end of the learning process. Then the linguistic variable is a tuple $<y_i, T^i, U^i>$, where y_i is the name of the linguistic variable, T^i is a basic term-set of values representing the names of fuzzy variables, the domain of which is the base set U^i of the attribute x_i. For example, let for a student, x_1 is knowledge of mathematics, due to the presence in the main educational goal of the basic quality of the activity competence "Ability to solve 100 square equations in a certain period of time." Then, y_1 is the "solve equations," i.e. the name of the linguistic variable; T^1 = {“can”} is the basic term-set of values of the attribute x_1; $U^1 = \{0, 1, 2, 3, \ldots, 100\}$ is the domain of the definition of a term set. Each term from the term set T^1 = {“can”} is a fuzzy variable defined as a tuple $< T^i_j, U, C^i_j>$, where T^i_j is the name of the fuzzy variable; U={u} is the domain of its definition; $C^i_j = \cup\mu_{Cij} / U = \mu_u/y$ is a fuzzy set on U, that describes the restriction on the possible value of the fuzzy variable T^i_j for all y belonging to the set Y. Here, μ_y: U→[0,1] is the degree of membership, which is a mapping of the set U onto the unit segment [0,1].

The degree of membership is a measure of how much the element $u \in U$ corresponds to a concept whose meaning is formalized by the set T. In our case, the value for the linguistic variable y_1 "solve equations" from the term set T^1_1 = {“can”} is a fuzzy variable with the corresponding names and restrictions on possible values. T^1_1 –“can” – is the name of the fuzzy variable; $U^1_1 = \{0, 1, 2, 3, \ldots 100\}$ is the domain of its definition, in this case, coinciding with the basic set of the linguistic variable y_1 – “the ability to solve quadratic equations,” but such a match is not always fulfilled. Then, perhaps the following comes: C^1_1= {<0.01/1>, <0.03/2>, <0.04/3>, … , <1/100> }.

The basic term-set of values of the attribute $x_1 - T^1$ – may contain more than one value, respectively, and the domain U^1_1 of each of these values may not coincide with the basic set of the linguistic variable. Values of membership function 0.01, 0.03, 0.04, … , 1 are taken as an example. Then, the educational goal can be defined as $\tilde{A}$; it is a fuzzy set of the second level of tuples $\mu_y(y)/y$ for all y belonging to the set Y. The value $\mu_y(y)$ is determined for each term from the term set T^i_j of the corresponding linguistic variable as μ_y: U→[0,1] and represents measure how much the element $u \in U$ corresponds to the concept, the meaning of which is formalized by the term T^i_j. In our example, for Y=$\{y_1\}$, the educational goal will be as follows: $\tilde{A}$={<0.02/1/“can”>, <0.03/2/“can”>, <0.03/3/“can”>, … <1/100/“can”>}. Thus, we pass from the “qualitative” description of the educational goal to its formalized description, which is a set (ideally a square matrix) of values of membership functions μ_y.

We extrapolate the obtained formalized description of the educational goal to the set of basic qualities of cognitive, activity, motivational, ethical, social and behavioral competencies. Let the set $X=\{X_1,...X_6\}$ be the set of basic qualities of cognitive, activity, motivational, ethical, social and behavioral competencies, consisting of subsets $X_1,...X_6$ of the following form: $X_1=\{x_{1-1},x_{1-2}, \dots , x_{1-n}\}$, where $x_{1-1},x_{1-2}, \dots , x_{1-n}$ are the core qualities of the respective competencies. Then, $Y=\{Y_1,Y_2,Y_3,Y_4,Y_5,Y_6\}$ is a set of linguistic variables, consisting of subsets of Y_1,Y_2,Y_3,Y_4,Y_5,Y_6, of the following form: $Y_1=\{y_{1-1},y_{1-2}, \dots , y_{1-n}\}$, where $y_{1-1},y_{1-2}, \dots, y_{1-n}$ are linguistic variables that describe the corresponding basic qualities of cognitive, activity, motivational, ethical, social, and behavioral competencies of professional competence, the formation of which is provided for by the educational program of the training direction "Pedagogical Education" of the profile "Technology." Then, if y_1 is “solve equations” is a linguistic variable that describes the basic quality “Ability to solve equations” of cognitive competence, for which T^1 = {“can’t”, “poorly able”, “satisfactory”, “good at”, “excellent at”} is the basic term-set of values, and $U^1 = \{0, 1, 2, 3, …., 100\}$ is the domain of the term set, where $U^1{}_1== \{0, 1, 2, 3, ….,20\}$, $U^1{}_2== \{20, 21, 22, 23, ….,40\}$, … , $U^1{}_5== \{80, 81, 82, 83, ….,100\}$ of $U^1== \{0, 1, 2, 3, ….,100\}$, then for $Y=\{Y_1,Y_2,Y_3,Y_4,Y_5,Y_6\} =\{\{ y_{1-1},y_{1-2}, ….., y_{1-n}\}, Y_1,Y_2,Y_3,Y_4,Y_5,Y_6 \}$ the educational goal will be as follows Ã={ {<1/0/“ cannot”>, <0.93/1/ “cannot”>, <0.84/2/“ cannot”>, … <0,01/100/”cannot”>, …, {<0.02/0/“can”>, <0.03/1/“can”>, <0.03/2/“can”>, … <1/100/ “can”>}, … ,{μ_{y-n}/y_6}}.

Teaching a student in the main educational program of the direction of preparation "Pedagogical education" of the profile “Technology,” we must form the maximum possible level of development of the basic qualities of cognitive, activity, motivational, ethical, social, and behavioral competencies in him/her. In a formalized pedagogical model, this corresponds to $\mu_y(y)/y =1$ for all y, belonging to the set Y. That is, the main educational goal, we denote it as $\tilde{A}^0$, can be formalized as $\tilde{A}^0$={ {<0/0/ “cannot”>, <0/1/ “cannot”>, <0/2/”cannot”>, … <0 /100/ “cannot”>, …, {<0/0/ “can”>, <0/1/ “can”>, <0/2/ “can”>, … <1/100/ “can”>}, … ,{1/ $U^6{}_{ma[}/y_6$}}. Then the structure and composition of each of the sub-goals $\tilde{A}_i$ from the set of sub-goals $\tilde{A} = \{\tilde{A}_1, \tilde{A}_2, …, \tilde{A}_n \}$, contained in the main educational program of the training direction “Pedagogical Education” of the profile “Technology” should be similar to the structure and composition of the main educational goal $\tilde{A}^0$ and differ only in specific values of the membership function $\mu_y(y)/y$. Only in this case, we will be able to carry out operations of comparison, inclusion, equality between a formalized description of the main educational goal and a formalized description of other sub-goals.

A change in the quantitative values of the membership function $\mu_y(y)/y$ will make it possible to conclude on the level of formation and the direction of development of the basic qualities of cognitive, activity, motivational, ethical, social, and behavioral competencies of a particular student. Then, the set of sub-goals $\tilde{A} = \{\tilde{A}_1, \tilde{A}_2, \dots , \tilde{A}_n \}$ contains the sub-goal $\tilde{A}_1$, for which the values of the membership function $\mu_y(y)/y$ for all basic qualities of cognitive, activity, motivational, ethical, social, and behavioral competencies will be "mirrored" relative to the main educational goal $\tilde{A}^0$. And some intermediate educational sub-goals $\tilde{A}_2, \dots ,$ $\tilde{A}_n$, in which membership functions for the minimum and maximum values of the fuzzy variable definition domain, take the values "0"; and for all other values, membership functions take a value other than "0." And the educational process is the process of moving a student through many sub-goals to achieve his/her main educational goal.

The main educational goal, the sub-system of the main educational program of the training direction “Pedagogical education,” the educational process are described by changing the quantitative parameter of the value of the membership function $\mu_y(y)/y$ on single scales. This makes it possible to transform a formalized pedagogical model into an exact mathematical model suitable for implementation by computer technology.

3. Results

We developed some theoretical provisions on the formalization of pedagogical models used in education by means of predicate logic language. On the example of the main educational program at the university, we formalized the educational model. In addition, we formalized descriptions of the main educational goal and the system of sub-goals of the pedagogical model as a set of fuzzy sets, the structure of which is similar to the structure of the main educational goal. Moreover, taking into account the requirements of the completeness of the pedagogical model, the system of sub-goals contains everything, including physically unrealizable but theoretically possible sub-goals. That is, the main educational goal and sub-goals differ only in the quantitative values of the membership function.

Practical testing of the proposed method was carried out on the example of the main educational program of the training direction “Pedagogical education” of the “Technology” profile, implemented at the Voronezh State Pedagogical University. Evaluation of the results was carried out as follows. Simultaneously with the linguistic description of the constructions of the natural human language, a formalized pedagogical model of the main educational program was presented for 517 students. At the end of each training lesson, the teacher graded the student not only in the "classical" form but also in the form of an assessment of the level of development of his/her basic qualities of cognitive, activity, motivational, ethical, social and behavioral competencies, in accordance with the quantitative scales of the corresponding basic qualities.

At the end of the work, all the grades received were summarized. And their presence in the sub-system of the main educational program was verified. As a result, the authors find that all the assessments received by students of the level of development of their basic qualities of cognitive, activity, motivational, ethical, social, and behavioral competencies were consistent in the formalized pedagogical model as one of the sub-goals, the achievement of which was envisaged by the formalized model. Finding an assessment outside the system of sub-goals was not fixed, which allowed us to conclude that the model matched the simulated educational process.

4. Discussion

The results of the study show that the process of converting the linguistic description given by the constructions of the natural human language, the educational program of an educational institution into a formalized pedagogical model, and then into an exact mathematical model is possible using the language of predicate logic. The resulting formalized pedagogical model fulfills the requirements for completeness and adequacy for such models. The language of predicate logic is close to natural language, which makes such models intuitive and easy to use. At the same time, the elimination of fuzziness in the linguistic descriptions given by the constructions of the natural human language makes it possible to relatively easily transform the resulting formalized pedagogical model into a form implemented by computer technology, to create the so-called “platform” for organizing the educational process for students to achieve the main educational goal.

In the course of the research, significant shortcomings inherent in the method under consideration were identified. First of all, this is the lack of unified pedagogical approaches in the interpretation of the pedagogical categories “competency” and “competence,” the basic qualities of competencies, as well as their quantitative or relative scales. Accordingly, when building a formalized pedagogical model, there is no unity among developers and users on this issue, which leads to doubt in the reliability and adequacy of the pedagogical model for the simulated educational process. And this imposes severe restrictions on the possibility of using the language of predicate logic to build formalized pedagogical models.

Similar studies are reported by Albert, D., Hockemeyer, C., Kickmeier-Rust, M. D., Nussbaumer, A., Steiner, C. M. [7]. The works indicate the high complexity of the obtained formalized pedagogical models and, as a consequence, the enormous complexity of their practical implementation. The general direction of further research is defined as a theoretical study of the correlation of concepts “competency” → “competence” → “basic quality,” the development of new methods and algorithms for modeling complex systems. These include the process of education, taking into account in a formalized pedagogical model not only current but also prospective levels of development of students' competencies in their chosen field of professional activity.

5. Conclusion

The contemporary economic basis of human society significantly changes the requirements for education as the most important social institution of human society. Education is moving from “traditional” forms to E-learning, the organization of which is impossible without the use of formalized pedagogical models. It is the formalized pedagogical models serving as the basis of personified education. Using predicate logic language to create formalized pedagogical models is the most promising area of research. Success in it will lead to a genuine individualization of education, the use of artificial intelligence systems in education, and the reduction of time and other material costs for the preparation of a competent specialist.

References

[1] Sleptsova, M. V. (2016). A competency-based approach to the organization of the educational process of vocational education. *Professional Education in the Modern World*, *6*(3), 408-413. Retrieved from https://elibrary.ru/item.asp?id=27158168.

[2] Khenner, E. K. (2018). Professional knowledge and professional competencies in higher education. *The Education and Science Journal*, *20*(2), 9-31. https://doi.org/10.17853/1994-5639-2018-2-9-31

[3] Sleptsova, M. V. (2019). Formation of students’ social competence in a virtual educational environment. *Education and Information Technologies*, *24*(1), 743-754. https://doi.org/10.1007/s10639-018-9798-z

[4] Sleptsova, M. V., & Sokolova, N. V. (2018). Formalization of students' individual educational objectives for e-learning. *Astra Salvensis*, *VI*, 67-74.

[5] Maestro-Prieto, J. A., & Simon-Hurtado, A. (2015). Learner-adaptive pedagogical model in SIAL, an open-ended intelligent tutoring system for first order logic. In C. Conati, N. Heffernan, A. Mitrovic, & M. Verdejo (Eds.), *International Conference on Artificial Intelligence in Education* (pp. 702-705). https://doi.org/10.1007/978-3-319-19773-9_96

[6] De Swart, H. C. M. (2018). *Predicate logic*. Retrieved from https://doi.org/10.1007/978-3-030-03255-5_4

[7] Albert, D., Hockemeyer, C., Kickmeier-Rust, M. D., Nussbaumer, A., & Steiner, C. M. (2011). E-learning based on metadata, ontologies and competence-based knowledge space theory. In D. Lukose, A. R. Ahmad, & A. Suliman (Eds.), *Third knowledge technology week* (pp. 24-36). Kajang, Malaysia. https://doi.org/10.1007/978-3-642-32826-8_3