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Implementation of developmental education in the digital learning environment

Igor Ivanov[a,1], Jesennia Cárdenas Cobo[b], Marina Kosonogova[c]

[a]Guayaquil business technology university #520, Guayacanes str., Urdesa Central, Guayaquil, 090150, Ecuador
[b]Milagro state university Campus of university, 1.5 km Via Milagro, Guayas, 091050, Ecuador
[c]Belgorod State Technologica University named after V.G. Shukhov, 46 Kostyukova street, Belgorod, 308012, Russia

Abstract

The problem of the formation of a pedagogical basis for the control of training in a digital learning environment is considered. It is proposed to model psychological and pedagogical processes on the basis of developmental education. The choice of the theory of developmental education is due to the need to ensure high rates of individualization of the educational process. The research is aimed at the development of theoretical, methodological and applied solutions in the field of disruptive education..

Keywords: NGDLE; developmental education; L. Vygotsky's zones of development; psychometrics; learning performance indicators

1. Introduction

At the present stage of development of the e-learning sphere, LMS solutions (eFront, Moodle, iSpring Learn, Talent LMS, Unicorn LMS), MOOC platforms (Coursera, Udacity, Udemy, MIT OpenCourseware, Stepik), NGDLE (Next Generation Digital Learning Environment) are used to organize a training. Such software classes are positioned as typical models of a digital learning environment. The concept of NGDLE system involves the integration of many educational services and individual platforms into a single ecosystem for the full realization of the idea of disruptive education. Typical components that can be integrated into the learning environment according to the NGDLE model perform following functions: creating training courses, monitoring and collection of operational data of learning activities, analysis of the quality and difficulty of content and evaluation tools,

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Corresponding author.
E-mail address: i.v.ivanov1960@gmail.com

accounting for achievements from different educational platforms, deep personalization of the learning process, and other. The new generation digital learning environment uses an active approach to learning, in which the focus is on the result and involvement in the educational process. The development of the theoretical and methodological basis regarding the formation of adaptive control actions in the digital learning environment of new generation depends on the solution which has following main tasks:

1. Modification of the e-learning experience on the basis of transferring scientifically-based theories of learning into the digital educational environment, for the formation of formalized pedagogical models of e-learning.
2. The development and study of models, methods and tools for the deep assessment of knowledge, skills of students data-driven on academic achievements and on interaction with the learning environment.

2. Immersing learning theories in a digital environment

Since the mid-20th century, the development of the principles of automated learning has been influenced by many pedagogical technologies and theories of learning. Choosing a pedagogical basis for the full implementation of adaptive, personalized learning, firstly needs to consider the possibility of immersing the theory of developmental education in a digital environment. This is true because of the fact that, within the framework of the theory, the connection between learning and the development of the individual is taken into account.

2.1. Review of the theory of developmental education

The meaning of developmental education (theory of development zones, social constructivism, “scaffolding”) is the sequential change of development zones as a result of mastering educational material of increasing the level of difficulty. At the level of actual development, materials with a level of difficulty no more δ_j can be mastered self-dependently. The zone of proximal development (ZPD) is opened from the zone of actual development. Having mastered ZPD with involvement of various types of assistance, the student “turns” it into a zone of actual development, etc.

The complexity of using the theory of developmental education is that the construction of the “development zone” does not lend itself to direct assessment and measurement. In abstracts and studies [1] on the subject of developmental education, various approaches to psychological and pedagogical diagnostics of the zone of proximal development are mainly described. They do not provide rigorous mathematical models for describing the characteristics of development zones, which is critical for generating control actions in the process of e-learning. The usage of the theory of development zones for the organization of automated learning is considered in a relatively small number of studies. [2]. At that there is only one specific criterion for the purpose of implementation e-learning in the zone of proximal development: if the subject solves the problems of the difficulty class $P(k)$ at the reference level, then it with the reliability of 80% solves problems 20% harder than $P(k)$. However, the usage of a fixed width of the development zone is a controversial point in terms of developmental education.

First of all, it is necessary to justify the fundamental possibility of transferring a certain theory of learning to the digital environment, i.e. select tools and components of the modern learning environment that are suitable for the implementation of key provisions of this theory. In the Table 1, using the example of the theory of development zones, the essential features of developmental education are highlighted, which cannot be abstracted from during the transition into the digital environment.

Table 1. Substantiation of the possibility of transferring the theory of developmental education to the digital environment

The trait of developmental education	Implementation option in digital environment
Identification of development zones is based on information about the scope and nature of corrective actions that the subject required to resolve problem.	A system of tips and other types of help. Software monitoring of user actions in a digital environment.
Timely assessment and regulation a zones of actual and proximal development.	Feedback mechanisms for optimizing the learning path after each learning step.
Compliance with the principle of visual training.	Interactive tools, gamification technologies.

2.2. Methodology

The solution to the problem of constructing a mathematical model of development zones is given on the theory of measuring latent variables and methods of computational psychiatry. The starting point is the thesis that the zone of proximal development is the distance between the levels of actual and possible development, i.e. can be described by the interval $\beta_s < ZPD \leq \beta_s + \omega_s$, where ω_s – threshold value characterizing the boundaries of the zone (width of the zone of proximal development for the s-th step of training); β_s – preparedness level at the s-th step of training.

To compare the width of the zone of proximal development of numerical value, one should proceed from the idea that the development zone is proportional to the level of preparedness:

$$\frac{\omega_s}{\beta_s} = k^*, \omega_s = \beta_{s+1} - \beta_s. \tag{1}$$

Here β_{s+1} and β_s – levels of preparedness achieved at the (s+1)-th and s-th training steps; k^* – proportionality coefficient, the applied meaning of which requires clarification.

In order to get away from the relationship between the width of the development zone and the training steps in expression (1) and obtain a more universal record, the following actions are performed: the level of preparedness at the s-th step of training is expressed through the initial level of preparedness β_0, logarithm is taken and the study applied the provisions of differential calculus. After transformations, the width of the development zone is presented

$$\omega = \omega_0 \cdot e^{C \cdot \beta}, \tag{2}$$

where ω_0 – width of the zone of proximal development with an average level of preparedness, for which in the theory of latent variables is taken $\beta = 0$ (logits); C – constant determining the growth rate of the ZPD.

In the formulas (1)÷(2), the development zone is presented through the indicator "level of preparedness", the numerical value of which is necessary to calculate the boundaries of the zone of proximal development. General approaches to quantifying level of preparedness are known [3]. The idea that preparedness in explicit form cannot be evaluated or measured gives the reason to take it for a latent variable. To implement developmental education in a digital environment, it is important that the level of preparedness model takes into account the pattern of user interaction with the training system and the use of prompts in the digital environment. From the point of view of computational psychometry [4, 5], the interaction pattern is described in the form of an array of data – a "digital footprint", including for each user: statistics on the passage of test tasks; dynamics of changes in indicators of educational activities; statistics of interaction with content and a learning platform or other. Thus, the data of the "digital footprint" are indicators of the level of preparedness. Therefore, a list of measured indicators is proposed for a formal description of the level of preparedness: number of skips for test tasks, number of answer option changes in the test, time of access to educational content when passing the test control, failure rate of passing the test, number of calls to external programs during the test control, time spent on passing the test control, and ect.

For the each s-th learning step, the metrics of user interaction with the learning platform and the results of the test tasks are recorded. In general, there is a tuple of indicators for a preparedness level model has the form $\langle y_{1,1} \dots y_{1,k}, y_{2,1} \dots y_{2,l} \rangle$, where $y_{1,1} \dots y_{1,k}$ – the block of indicators with the results of test tasks, $y_{2,1} \dots y_{2,l}$ – the block of behavioral factors of Table 3. The data of the every learning step is discretized and processed using a suitable IRT model included in the measuring apparatus of the theory of latent variables:

$$P\{x_{ij} = x\} = \frac{e^{-\tau_{1j} - \tau_{2j} - \dots - \tau_{xj} + x \cdot (\beta_i - \delta_j)}}{\sum_{x'}^{m_j} e^{-\tau_{1j} - \tau_{2j} - \dots - \tau_{xj} + x' \cdot (\beta_i - \delta_j)}}. \tag{3}$$

Here x – indicator's gradation based on discretization; x_{ij} – response of the i-th student to the j-th indicator; $P\{x_{ij} = x\}$ – the probability of the i-th student choosing the option x of j-th indicator; δ_j – difficulty level of indicator; τ_{xj} – relative difficulty level of the x-th gradation of the j-th indicator, understood as an increment in the level of preparedness necessary for the transition between gradations; m_j – index variable accepting all options of the j-th indicator.

We assume that in all the dependencies that describe the parameters of the zone of proximal development, the level of preparedness is measured on the basis of (3) taking into account the difficulty level of the tasks being solved, the factor of using different types of help and other user interactions with the learning environment.

To select the coefficients ω_0, C of expression (2), an algorithm is proposed that includes 4 steps.

Algorithm 1. Selection of parameters of the zone of proximal development:

1. To prepare assessment tools with a known level of difficulty δ for measuring the level of preparedness of a group of subjects. The validity and reliability of the assessment tools should be checked to exclude extremely difficult or easy test tasks, and also to balance the set of tasks by the percentage of tests of different difficulty levels. To measure the level of preparedness β and postpone the results on a single scale in logits, which is adopted in the theory of measurement of latent variables.
2. In the vicinity of zero to select two points on the preparedness level scale that form the range [$-\beta^*$; $+\beta^*$] with the highest frequency of measurement results β.
3. To choose an additional reference point with an arbitrary value of the level of preparedness β_{add}. To select n subjects with a level of preparedness $\beta_i \approx \beta_{add}$ ($i = 1..n$). Successively to present to a group of n subjects tasks of increasing difficulty level (the initial difficulty level δ_0 should be β_{add}). To fix the value of the difficulty level δ_{lim} at which 93-95 % of the group of subjects is unable to successfully complete the tasks. To comply with the concept of developmental education, tests should be carried out in conditions when the system of help and tips is available during the completion of test tasks.
4. Find coefficients ω_0, C from the solution of the system of equations

$$\begin{cases} \omega_0 \cdot e^{-\beta^* \cdot C} \cdot 1{,}2 = \omega_0 \cdot e^{+\beta^* \cdot C}, \\ \omega_0 \cdot e^{\delta_0 \cdot C} = \delta_{lim} - \delta_0, \end{cases} \tag{4}$$

where 1,2 – the coefficient which is taken from didactic considerations that, with the level of preparedness achieved, the subject is potentially successful at mastering the material by an average of 20% more difficult.

The second equation in system (4) is compiled from considerations that tasks with a difficulty level $\delta_0 < \delta \leq \delta_{lim}$ (logits) are in the zone of proximal development of each i-th subject from the group with $\beta_i \approx \beta_{add}$ ($i = 1..n$). The application of the theory of latent variables allows to consider the parameters β^*, ω_0, δ_0 and δ_{lim} from this system of equations on a single scale in logits.

2.3. Practical results

The introduction of the model of the zone of proximal development allows to expand the digital model of the student in terms of taking into account individual characteristics that affect the success of training. Therefore, it is further appropriate to consider the application of the constructed pedagogical model for adaptive control of e-learning (Fig. 1) [6]. Blocks 1-8 according to Fig. 1 are intended for introducing into the control loop of developmental education the individual parameters of the test subject: the level of preparedness and characteristics of the zone of proximal development. The main logic of decision making on the formation of the trajectory fragment us at the s-th step is laid down in blocks 10-13. Block 12 should contain the implementation of the one-step or multi-step optimization method. Moreover, equality constraints, inequality constraints, and the optimality criterion could use the parameters of development zones to increase the adaptability of the management process.

To assess the appropriateness of applying the model of the zone of proximal development, the following method is proposed. As experimental material, data on the results of the learning activity of N test subjects is used, organized in the form of a two-dimensional matrix Y with dimension $N \times (k+l)$. Indices of the matrix are test subjects and fixed indicators of learning activity from a tuple $<y_{1,1} \ldots y_{1,k}, y_{2,1} \ldots y_{2,l}>$, where $y_{1,1} \ldots y_{1,k}$ – block of indicators with the results of test tasks, $y_{2,1} \ldots y_{2,l}$ – block of behavioral factors. If it is impossible to fix any behavioral factors in the process of e-learning, they should be excluded from further consideration. The results of learning activities should be ordered by topics or sections of the studied discipline. The following hypothesis is subject to verification: the level of preparedness of the majority of test subjects achieved during the developmental education is a certain percentage higher than according to the results of e-learning without taking into account the ZPD.

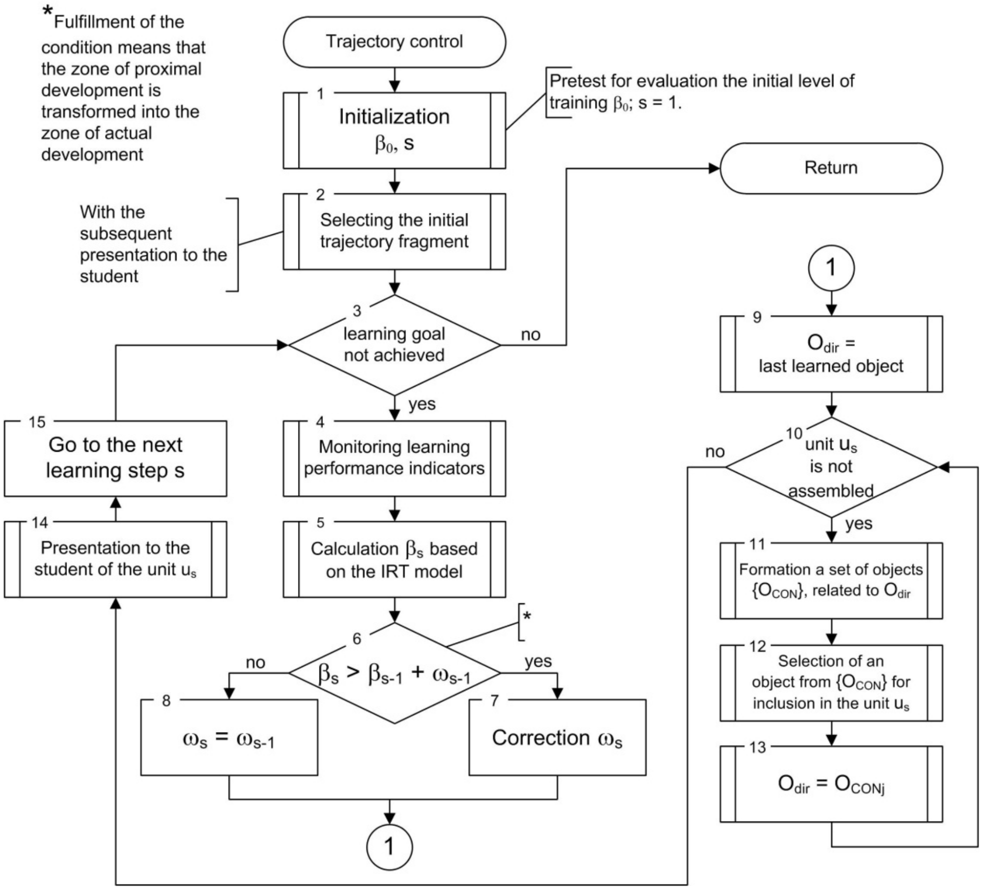

Fig. 1. The adaptive control algorithm, which implements developmental education

Algorithm 2. Assessment of the appropriateness of applying the model of the zone of proximal development:

1. Calculation according to the IRT model (3) of the preparedness levels β_i of test subjects (i = 1..N) and the difficulty levels δ_j of indicators (j = 1..k+l) based on the results of a study of all themes of discipline.
2. Preparation for simulation modeling of the developmental education process. For the initial level of preparedness for each user is taken $\beta_z^{(0)}$ (z = 1..N), calculated according to the results of the study of the first topic of the discipline.
3. The steps of the algorithm according to Fig. 1 are performed for each test subject. In block 4, instead of monitoring the indicators of learning activity, they are generated. To do this, a row is selected from the original matrix Y for which $\beta_i \approx \beta_z^{(0)}$ ($i \neq z$). This paragraph is repeated until all blocks of discipline are exhausted. As a result, the level of preparedness of the test subject after s training steps reaches the value $\beta_z^{(s)}$.
4. Comparison for each test subject of the values of preparedness levels from the 1st and 3rd steps. Confirmation or refutation of a hypothesis.

To substantiate the theoretical conclusions on the use of the model of the development zone (2) for adaptive learning (according to the algorithm in Fig. 1), the following experimental material was used: 1) physics learning outcomes of 310 students from State University of Milagro (Ecuador); 2) computer science learning outcomes of 1159 students from BSTU named after V.G. Shukhov (Russia). In the first case, the monitoring of academic achievements was carried out on the basis of 4 blocks of online tests with 10 questions and one behavioral indicator - testing time. In the second case – based on 4 blocks of material, including 60 test items and theoretical content, as well as behavioral indicators. In each case, the indicators values recorded during the program monitoring were processed using the IRT model (3) in the RUMM2020 software package. The resulting ranges of difficulty levels δ_j of the tasks and levels of preparedness β_i of the subjects were needed for the experimental selection of the parameters for model of the zone of proximal development. Range of changes $\delta \in$ [-3,1; 2,5] and $\beta \in$ [-2,7; 4,0] logits recorded at State University of Milagro, at BSTU named after V.G. Shukhov – $\delta \in$ [-4,8; 6,5] and $\beta \in$ [-5,0; 6,0] logits. Based on Algorithm 1 and the data presented, the following model parameters (2) were obtained: 1) ω_0 = 0,30, C = 0,24; 2) ω_0 = 0,27, C = 0,26. The proximity of the parameter sets can be explained by the fact that at both sites the results of the learning activities of medium-trained students were mainly used. Let us accept the differences between the parameter sets as insignificant, since the sequences of the values of the width of the zone of proximal development obtained for the range $\beta \in$ [-6,0; 6,0] logits, have close estimates of mathematical expectations and variances: 1) m = 0,4052, D = 0,0047; 2) m = 0,4256, D = 0,0050.

The consistency of the model of the zone of the nearest development was checked according to the data State University of Milagro. Based on simulation modeling of the developmental education (according to Fig. 1, with the development zone parameters ω_0 = 0,30, C = 0,24), it was found that for 59% of the students from the initial sample (N = 92 people), the final level of preparedness may increase by 4,3-6,7%. The effect is achieved by presenting at the each training step such test tasks, the level of difficulty of which is comparable with the level of preparedness achieved. To improve the grade obtained, at first the expanded model for monitoring academic achievement could be used. This refers to the calculation of the level of preparedness according to the model (3) taking into account the lots of behavioral indicators. Secondly, for developmental education, assessment tools should be used that cover a wide range of changes in the level of preparedness. In other words, the situation when the difficulty level of the evaluative tools is concentrated in a narrow range of the measurement scale should be excluded.

3. Conclusion

The article discusses the process of transferring a scientifically based theory of developmental education to a digital learning environment. As a result, the mathematical dependence (2) is obtained, which allows numerically expressing the width of the zone of proximal development. The algorithm is proposed for the experimental selection of the model parameters of the zone of proximal development, knowing the level of preparedness of subjects and the difficulty level of the assessment tools. The model of the development zone (2) was built into the algorithm of adaptive control of the developmental education process (Fig. 1). Further research may be related to the construction of a whole family of models of the zone of proximal development. The relevance of this task is justified by the fact that the parameters and structure of the model of developmental education can vary depending on the age group, type of temperament, level of development of cognitive functions and other features.

Since development zones relate to the personality and psychological characteristics of the individual, the usage of the model (2) in organizing e-learning can improve the adequacy of modeling of psychological and pedagogical processes in a digital environment. This hypothesis was confirmed in the framework of simulation modeling of the developmental education process (Algorithm 2). In other words, the model of the development zone can be taken as the basis for the method of managing the learning process, the method of forming studying and controlling influences, as well as the adaptation model.

References

[1] Hakkarainen, Pentti, and Irina Korepanova. (2009) "The status of the Vygotsky's "Zone of proximal development" in Russian psychology today." *Journal of Russian and cast European psychology* **47(6)**: 3–8.

[2] Lin, H.-Y., Tseng, S.-S., Weng, J.-F., and Su, J.-M. (2009). "Design and Implementation of an Object Oriented Learning Activity System." *Educational Techonology & Society* **12(3)**: 248–265.

[3] Maslak, Anatoly (2003) "Rasch Measurement of Latent Variables in Education." IV IOSTE Symposium for Central and East European Countries. KSU, Kursk, Russia.

[4] Wilson, Kevin, and Zack Nichols. (2015). "The Knewton Platform. A General-Purpose Adaptive Learning Infrastracture." A Knewton paper.

[5] Abbakumov, Dmitry, Piet Desmet, and Wim Van den Noortgate. (2018). "Measuring student's proficiency in MOOCs: Multiple attempts extensions for the Rasch model." *Heliyon* **4(12)**: 1–15. doi.org/10.1016/j.heliyon.2018.e01003

[6] Kosonogova, Marina (2016). "Method and means of educational trajectory control in e-learning systems (doctoral thesis)." The Southwest State University (SWSU), Kursk, Russia.