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DIAGNOSTIC SUPPORT OF AN INTELLIGENT TUTOR SYSTEM FOR TEACHING SKILLS TO SOLVE ALGEBRAIC EQUATIONS

Although all advantages of a standard approach to teaching students new skills, we are increasingly faced with problems such as the inability to pay an equal amount of attention to many students, to work through and unambiguously highlight all possible problems and mistakes, to close knowledge gaps. Also, all these difficulties are becoming even more urgent given the current state of affairs in the world and the global transition to an online learning format. As a possible solution to the problem, one can consider the creation of independent intelligent systems capable of taking on a part of the load of teachers and automatically participating in the process of teaching students. The subject of research in this article is the process of analyzing the steps for solving algebraic equations using the Lobachevsky-Graeffe-Dandelen method. The goal is to model the process of solving algebraic equations and to identify all possible steps, difficulties and problems in solving such problems. Objective: development of a system capable of monitoring the execution of all necessary steps for a given solution, identifying and classifying possible student mistakes in the process of mastering the skill and work them out. In the process of the task, the following results were obtained: one possible solution for learning to solve an n-degree algebraic equation using the Lobachevsky-Greffe-Dandelen method has been described. On the basis of the signal-parametric approach to diagnostics of faults in dynamic systems the mathematical diagnostic models are created which allow detecting classes of errors by comparing the results of Student's calculations and the results of system calculations. The features and possible difficulties of application of the proposed diagnostic models are presented. An intelligent self-contained tutor system was developed and integrated into the work at practical classes on "Theory of Automatic Control" by 3rd year students of the National Aerospace University.

Keywords: Intelligent tutor system; student mistake; diagnostic model.

Introduction

A key intellectual part of the computer tutor system is one of the most significant and key points of a computer-based learning system that incorporates the experience, knowledge, and skill of teachers is the diagnostic service. With the help of such a service, it is possible not only to detect a student's error but also to diagnose its cause, to determine for this student a sequence of training adapted to him.

There are a lot of scientific works devoted to the development of such diagnostic services for intellectual tutor systems. We can distinguish the 2 largest groups: some of them are based on a comparison of perturbed and reference models [1 - 5], and the other group is based on the Bayesian approach [6, 7].

At the moment, many possible implementations of intelligent learning systems have been described. Such implementations as ActiveMath, Ms. Lindquist, Carnegie Learning's Cognitive Tutors, ALEKS [8] include diagnostic functions and teach mathematical problem-solving.

Diagnostic services in such systems are divided into two levels: the first to analyze certain steps of the student in solving a specific mathematical problem, the second to analyze the general skills of the student.

But there are also opponents of diagnostic services in learning systems. For example, in [9] the authors hold the opinion that the diagnostic aspect is not needed at all, since the educational process is divided into small steps and instantaneous feedback is used to prevent error accumulation. We do not support such an opinion for the following reasons. First, the introduction of intermediate results leads to additional costs of such a valuable resource as time. Second, in certain cases there are several correct orders of calculations [10] and it does not seem possible to clearly define the decomposition of the learning process. Third, even in a small step, there is the possibility of making a serious error, such as approximating 3.445 to 3.5 or to 4.

This study is justified for the following reasons. There are virtually no descriptions of errors made by students of educational institutions when solving problems in practice. In the publications that have been devoted to the diagnostic functions of an intellectual teacher, descriptions of student errors are usually limited to primitive mathematical operations. Mathematical tools for diagnosing errors are also poorly covered at present.

This paper describes one possible solution for teaching skills for solving an n-power algebraic equation using the Lobachevsky-Greffe-Dandelen method. It is used in practical classes on "Automatic Control Theory" by third-year students at the National Aerospace University.

The Lobachevsky-Greffe-Dandelen method [11] was chosen as the basis for solving the n-power algebraic equation because of its relatively simple calculation scheme and its importance for solving stability problems due to the possibility to determine both complex and real roots.

Problem definition

1. Analyze the students' written solutions of algebraic equations of n power and, based on the results, find and determine the class of the student's error.

2. Based on the signal-parametric approach to fault diagnosis in dynamic systems [13] create mathematical diagnostic models, whose main task will be to identify classes of student errors by comparing the final results of the student and the final results of the system.

3. To develop intelligent tutor system for Lobachevsky-Greffe-Dandelen method learning which includes following main functions:

a) support student by guide which covered theoretical questions appeared during Lobachevsky-Greffe-Dandelen method learning;

b) task solution sequence control;

c) student knowledge and skills step-by-step diagnosis;

d) student knowledge and skills remediation by feedback introducing.

Computer model description
of Lobachevsky-Greffe-Dandelen method

Let n, g be integer and positive numbers, h be integer nonnegative number,

$$b \in \{0,1,...,h\}, j \in \{0,1,...,n\}, l \in \{1,...,n\},$$
$$k \in \{1,...,g\} \ v \in \{g\text{-}1, g\}.$$

Let us consider the two simplest cases, when equation $a_0 x^n + a_1 x^{n-1} + ... + a_n = 0$, which coefficients are real numbers, has all real roots or only one pair of complex roots.

Let's introduce an auxiliary function $r\_f(x,h)$ to present by the rounding rules any real number x with a floating decimal point to within h digits after the point:

$$r\_f(x,h) = (-1)^t * (z_0 + z_1 * 10^{-1} + $$
$$ + z_2 * 10^{-2} + ... + z_h * 10^{-h}) * 10^p,$$

where $z_b \in \{0,1,...,9\}$, $t \in \{1,2\}$, p is a integer number, $(z_0 > 0) \oplus (\forall b z_b = 0)$.

Let's $A_{(0,j)} = a$. Then coefficients of reformed equations can be calculated by formula

$$A(k,j) = r\_f(A_{(k-1,j)}^2 + $$
$$ + 2 \sum_{s=1}^{j} (-1)^s A_{(k-1,j-s)} A_{(k-1,j+s)}, h),$$

where $A_{(k-1,c)} = 0$, if $(c < 0) \oplus (c > n)$.

Condition of coefficients calculation interrupting is

$$\forall j \forall v \ ((A_{(v,j)} > 0) \Rightarrow (r\_f(A_{(g,j)}, h) = r\_f(A_{(g-1,j)}^2, h))).$$

Real roots calculation is performed by formula

$$x_l = r\_f(\sqrt[2^g]{\frac{A_{(g,l)}}{A_{(g,l-1)}}}, h),$$

at that $\forall v(A_{(v,l)} > 0) \wedge (A_{(v,l-1)} > 0)$. Sign of real root is determined by substitution. At complex roots calculation $x_l = \alpha + i\beta$ and $x_{l+1} = \alpha - i\beta$ at first $\rho = |x_l| = |x_{l+1}|$,

$$p^2 = r\_f(\sqrt[2^g]{\frac{A_{(g,l)}}{A_{(g,l-1)}}}, h) \text{ is computed,}$$
$$\text{where } \exists v \ (A_{(v,l)} < 0).$$

Then

$$\alpha = r\_f(-\frac{1}{2}\left(\frac{a_1}{a_0} + x_l + ... + x_{l-1} + x_{l+2} + ... + x_n\right), h)$$

and

$$\beta = r\_f(\sqrt{p^2 - a^2}, h) \text{ are computed.}$$

Experimental results

To determine what kind of problems students have in solving algebraic equations, we experimented.

Thirty-seven third-year students studying Automated Control Systems took part in it. There were 20 different equations with three roots. Each equation had either 3 real roots or 1 real and 2 complex roots. Each student was asked to solve 1 equation. The required calculation accuracy was 4 significant positions.

To identify the maximum number of errors when analyzing students' work, we continued to simulate student calculations even after errors were detected. Thus, we identified 105 different errors.

In terms of error causes, all errors can be divided into two classes: procedural errors and misconceptions [2].

Concerning to place of appearing all mistakes can be divided into two classes: general (for example, rounding mistakes, misspelling, and so on) and specific for a concrete place (for example, lack of complex root existence conditions knowledge)

Below discovered classes are presented ordered by some mistakes that appeared in our experiment (table 1).

Let's uncover the essence of the presented classes.

The "Error in Calculating a Complex Root with an Imaginary Part" class describes a situation where the student forgets that the absolute value of the complex root is the square directly calculated, and thus substitutes instead of at β computing.

The "Failure to meet the Root Squared Ending condition" class is associated with ignorance of the fact that not all significant positions of positive coefficients coincided with significant positions of the squared coefficients obtained in the previous step.

"Misspelling" class includes such typical spelling or input errors as single transcription (4 times), symbol deletion (3 times), adjacent symbols transposition (once), multiple transcriptions (once), and symbol addition (once).

"Errors associated with calculating roots" are calculating the 2g-th root instead of calculating the 2g-th root (8 times) and calculating the roots of the equation without calculating the radical (3 times).

The "Errors in calculating the product of doubled coefficients" class includes errors such as losing one of the multipliers (4 times), using the current upper coefficient instead of the upper left (1 time), using the current coefficients instead of the upper left (1 time), using the current left coefficient instead of the upper left (1 time), and using the initial coefficient (1 time). "Rough calculations" cover rounding errors (5 times) and ignorance of calculation accuracy requirements (3 times).

The class "Ignorance of conditions for the existence of complex roots" is associated with the calculation of complex roots, when the condition of existence (changing the sign of the coefficients in one of the columns) is not satisfied.

Errors in the class "Inverted formula for calculating roots" are caused by mirroring the initial coefficient. The class "Incorrect calculation of coefficients" means fourth-degree multiplication instead of squaring (3 times).

"Incorrect coefficient exponentiation" class means raising to the fourth power instead of squaring (3 times).

"Loss of a sign at calculation" is one of the most common classes of mistakes [12].

"Redundant iteration" class describes the situation when a student continues calculation when the condition of interrupting is true.

"Mistakes at 2^g-th root calculation" class describes situation when student calculates 2^{g+1}-th root (2 times).

"Displaced quotient calculation" class appeared 2 times at p^2 calculation when student took $\frac{A_{(g,3)}}{A_{(g,1)}}$ instead of $\frac{A_{(g,2)}}{A_{(g,0)}}$.

"Mistakes at exponent calculation" class describes situations when significand is correct but exponent isn't.

Table 1

Classes of the mistakes

Class of the mistakes	Number of mistakes	%
Mistake at imaginary part complex root calculation	14	13.3
Non-compliance with the condition of root squaring end	12	11.4
Mistakes connected with root squaring misunderstanding	11	10.5
Misspelling	10	9.5
Mistakes at doubled coefficients product calculation	8	7.6
Rough calculations	8	7.6
Unrecognized mistakes	6	5.7
Inverted formula for roots calculation	6	5.7
Lack of complex root existence conditions knowledge	5	4.8
Loss of sign at calculations	5	4.8
Redundant iteration	5	4.8
Incorrect coefficient exponentiation	3	2.9
Mistakes at 2^g-th root calculation	2	1.9
Displaced quotient calculation	2	1.9
Mistakes at exponent calculation	2	1.9
Others	6	5.7

"Others" class include such mistakes as incorrect power dividing ($\frac{10^{28}}{10^{14}} = 10^2$ (once)), β is calculating by formula for p^2 (once), incorrect sign determining of real root (once), incorrect sequence of operations ($(-10)^2 = -100$ (once)), lack of main algebra theorem knowledge (calculations only 2 roots instead of 3 (once)), taking 2^g-th root from one coefficient but not from quotient (once).

As a result of the tests, we got the maximum number of mistakes made by one student equal to 6 (3 times). For example, one student first raised to the fourth power instead of squared, then made a typo when writing one digit, then used the current value instead of the upper left coefficient, then used an inverted formula, then showed no understanding of the conditions of the existence of the complex root, and finally made an error when calculating the complex root by the imaginary part.

Diagnostic models

Diagnostic model (DM) is a mathematical model which connects mistake with its symptom and allows solving of inverse problem [13, 14].

Let's introduce table of symbols: $\tilde{x}$ is a value calculated by student, $\hat{x}$ is a reference value calculated by tutor program,

$$m(r\_f(x, h)) = z_0 + z_1 * 10^{-1} + \\ + z_2 * 10^{-2} + \ldots + z_h * 10^{-h}$$

and $ex(r\_f(x, h)) = p$ are two auxiliary functions.

Then DM for mistake detecting is

$$r\_f(\tilde{x}, h) \neq r\_f(\hat{x}, h).$$

After mistake detecting we should identify its cause. So we use DMs for class finding. For instance, DM for finding "Mistake at imaginary part complex root calculation" class is $\tilde{\beta} = r\_f((\sqrt{\hat{p}^2 - \hat{a}^2}, h))$.

DM for finding "Non-compliance with the condition of root squaring end" class is

$$(\widetilde{z_0} = \widehat{z_0}) \wedge (\widetilde{p_0} = \widehat{p_0}) \wedge (\exists s \in \{1, 2, \ldots, h\}\ \widetilde{z_s} \neq \widehat{z_s}).$$

DMs for "Mistakes connected with root squaring misunderstanding" are defined as follows

$$\widetilde{x_l} = r\_f(\sqrt[2^g]{\frac{\widehat{A}_{(g,l)}}{\widehat{A}_{(g,l-1)}}}, h), \tilde{p}^2 = r\_f(\sqrt[2^g]{\frac{\widehat{A}_{(g,l+1)}}{\widehat{A}_{(g,l-1)}}}, h)$$

describe 2^g-th root computing instead of 2^g-th root computing

$$\tilde{x}_l = r\_f(\frac{\widehat{A}_{(g,l)}}{\widehat{A}_{(g,l-1)}}, h), \tilde{p}^2 = r\_f(\frac{\widehat{A}_{(g,l+1)}}{\widehat{A}_{(g,l-1)}}, h)$$

are defined for situation when roots or $\tilde{p}^2$ are calculated without computing of radical.

DMs for "Mistakes at doubled coefficients product calculation" class are:

$$\widetilde{A}(k, j) = r\_f(\widehat{A}^2_{(k-1,j)} + \\ + \sum_{s=1}^{j} (-1)^s \widehat{A}_{(k-1,j-s)} \widehat{A}_{(k-1,j+s)}, h) - \text{loosing of 2;}$$

$$\widetilde{A}(k, j) = r\_f(\widehat{A}^2_{(k-1,j)} + \\ + 2\sum_{s=1}^{j} (-1)^s \widehat{A}_{(k-1,j-s)}, h) - \text{loosing of right} \\ \text{multiplier;}$$

$$\widetilde{A}(k, j) = r\_f(\widehat{A}^2_{(k-1,j)} + \\ + 2\sum_{s=1}^{j} (-1)^s \widehat{A}_{(k-1,j-s)} \widehat{A}_{(k-1,j+s)}, h) - \text{using current} \\ \text{left coefficient instead of top left one.}$$

DMs for "Rough calculations" class are defined by two following models

$$(r\_f(\tilde{x}, h) - r\_f(\hat{x}, h) = \\ = -1 * 10^{ex(r\_f(\hat{x},h))-h}) \wedge (\hat{z}_{h+1} \geq 5)$$

serves for finding mistakes in rounding, where $\hat{z}_{h+1}$ is a stored reference (h+1) significant position. For instance, rounding mistake was made when student rounds 1.4445 to 1.444.

DM for finding mistakes connected with ignorance of computing accuracy requirements is defined as follows

$$r\_f(\tilde{x}, h) = r\_f(\hat{x}, h),\ 0 \leq b < h.$$

Using $1.6 \cdot 10^7$ instead of $1.631 \cdot 10^7$ can be seen as an example of such mistake.

To find single transcription we use DM which defined as

$$\exists b(\widetilde{z_b} \neq \widehat{z_b}) \wedge (\forall s \in \{0, 1, \ldots, h\} - \{b\}\ \widetilde{z_s} = \widehat{z_s}).$$

Adjacent symbols transposition can be found by using

$$\exists s \in \{0, 1, \ldots, h-1\}(\tilde{z}_s \neq \hat{z}_{s+1}) \wedge (\tilde{z}_{s+1} \neq \hat{z}_s) \wedge \\ \wedge (\forall w \in \{0, 1, \ldots, h\} - \{s, s+1\}\ \tilde{z}_w = \hat{z}_w).$$

For finding all of "Misspelling" mistakes similar strings detecting methods [16] can be used.

DM for "Inverted formula using for roots calculation" class is

$$\widetilde{x_l} = \pm r\_f(\sqrt[2g]{\frac{\widehat{A}_{(g,l-1)}}{\widehat{A}_{(g,l)}}}, h).$$

DM for "Lack of complex root existence conditions knowledge" class is defined as

$$(I(\widetilde{x_l}) \neq 0) \wedge (\forall j \forall v (\widehat{A}_{(v,j)} > 0)),$$

where $I(\widetilde{x_l})$ is an imaginary part of x_l root.

We define "Redundant iteration" as

$$\forall j \forall s \in \{g-2, g-1\}((\widehat{A}_{(s,j)} > 0) \Rightarrow$$
$$\Rightarrow (r\_f(\widehat{A}_{(g-1,j)}, h) = r\_f(\widehat{A}^2_{(g-2,j)}, h))).$$

$$\widetilde{x_l} = r\_f(\sqrt[2g]{\frac{m(r\_f(\widehat{A}_{(g,l)}, h))}{m(r\_f(\widehat{A}_{(g,l-1)}, h))} * 10^{\frac{ex(r\_f(\widehat{A}_{(g,l)}, h))}{ex(r\_f(\widehat{A}_{(g,l-1)}, h))}}}, h)$$

serves for finding of incorrect power dividing mistakes.

One of the possible scenarios of obtained DM application is presented in fig. 1 by the example of student's coefficient $A_{(b,j)}$ calculation.

If the student made a mistake, the program will tell the user that an error was made, analyze the error, and suggest that the user try again. If the error is repeated, the program will report the error again, analyze the error and suggest repeating the steps. And only if the student continues to make a mistake and reaches step i, the program will give a diagnostic message about the error, indicating its class.

This approach corresponds to the principle that the student should first work on the mistakes without help. Therefore, the diagnostic message with a hint about the cause of the error is not given immediately, but instead the student is given the opportunity to find and correct the error - thus, to work on his skills independently and to better understand the problem. The results of the error analysis performed by the program at each step are saved in the student's model for further training of the system.

All of the diagnostic models considered were created taking into account only one mistake made by a student, although students sometimes make several mistakes.

The arguments for this assumption are:

1. The probability of several mistakes is much smaller than the probability of one mistake, because per<per*per*...*per, where per is the probability of one mistake.
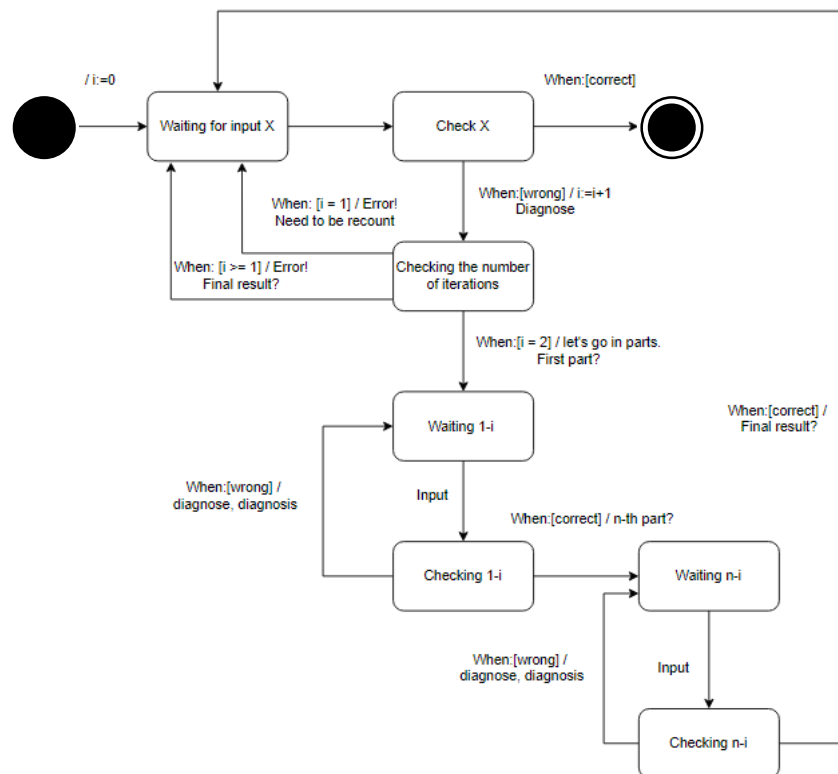

Fig 1. Fragment of diagnostic models application scenario

2. Even for not too complex formulas a huge number of alternative solutions appear when taking into account several errors, which complicates the processing many times [10].

3. If the diagnosis cannot be determined, the program will prompt the student to repeat the calculations in steps [2] or to do the diagnosis in conversation with the student [15].

Note that several diagnoses can be assumed, e.g., rounding from 1.3005 to 1.3 can be interpreted either as a rounding error or ignorance of calculation accuracy requirements. In this case, the diagnosis is stored in the student's model as d1 $\oplus$ d2 and can be determined more accurately with additional questions to the student.

We have implemented in Delphi 6.0 the first version of such an intelligent tutoring system, screenshots of which are shown in fig. 2.

This system includes all the previously mentioned diagnostic models. When the system detects students' misunderstanding of the goal of the task, it returns them to learning the theory.

The system is used in practical classes on "Theory of automatic control" by third-year students of our university. The following can be noted as a result of using the system. Firstly, even backward and lazy students are more motivated to work in the tutor system. Secondly, each student correctly solves his problem without the help of the teacher, which is especially useful in the current environment of online work.

Conclusion

The development and implementation of diagnostic services are some of the main problems in the development of intelligent learning systems. The main achievement of this work is, firstly, the results of the study of student errors, and secondly, based on these results, diagnostic models for determining classes of student errors were proposed.

The plan is to implement the diagnostic models in one of the interpreted languages and store these models in a database. This approach will allow us to both augment and modify the models without any significant changes in the program code. In addition, the software shell in automatic (self-learning mode) [1] will be able to generate new diagnostic models, store them in the selected database, and already based on this correctly interpret them. For example, the part of the proposed models that is related to the lack of operations can be extracted from the reference model that we have proposed. We are going to create models to analyze such general skills as - learning ability, independent work, attentiveness assessment, and others. The use of dynamic Bayesian networks and analysis of student queries using SQL can be considered as promising research in this direction [16, 17].

References (GOST 7.1:2006)

1. Kulik, A. Rational intellectualization of aircraft control: Resources-saving safety improvement [Text] / A. Kulik // Green IT Engineering: Components, Networks and Systems Implementation / V. Kharchenko, Yu. Kondratenko, J. Kacprzyk. – 2017. – P. 173-192. DOI: 10.1007/978-3-319-55595-9_9.

2. Чухрай, А. Методология обучения алгоритмам [Текст] : моногр. / А. Чухрай. – Харьков : Нац. аэрокосм ун-т им. Н. Е. Жуковского "Харьков. авиац. ин-т", 2017. – 336 с.

3. How Do Students Perceive Their Own and Their Peers' Progress in E-Learning? [Text] / S. Somyürek, et al // International Journal of Information and Learning Technology. – 2021. – Vol. 38, No. 1. – P. 49-74. DOI: 10.1108/IJILT-05-2020-0073.

4. A solution-based intelligent tutoring system integrated with an online game-based formative assessment: development and evaluation [Text] / D. Hooshyar, R. B. Ahmad, M. Yousefi, M. Fathi, A. Abdollahi, S. J. Horng, H. Lim // Educational Technology Research and Development. – 2016. – Vol. 64, Iss. 4. – P. 787-808. DOI: 10.1007/s11423-016-9433-x.
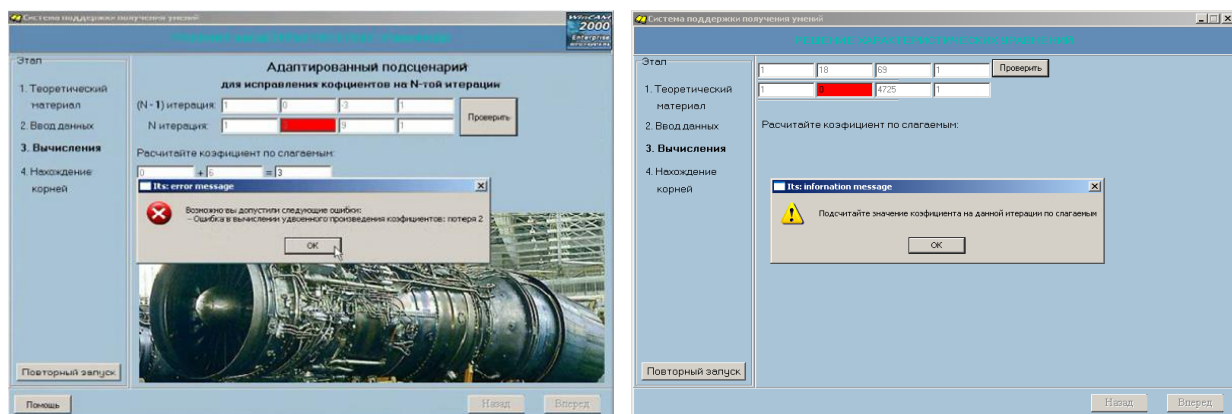

Fig 2. Intelligent tutor system screenshot

5. A flowchart-based intelligent tutoring system for improving problem-solving skills of novice programmers [Text] / D. Hooshyar, R. B. Ahmad, M. Yousefi, F. D. Yusop, S.-J. Horng // Journal of Computer Assisted Learning. – 2015. – Vol. 31, Iss. 4. – P. 345-361. DOI: 10.1111/jcal.12099.

6. A flowchart-based programming environment for improving problem solving skills of Cs minors in computer programming [Text] / D. Hooshyar, R. B. Ahmad, S. Shamshirband, M. Yousefi, S. J. Horng // The Asian International Journal of Life Sciences. – 2015. – Vol. 24, No. 2. – P. 629 – 646.

7. Collins, J. Adaptive assessment using granularity hierarchies and Bayesian nets [Text] / J. Collins, J. Greer, S. Huang // Intelligent tutoring systems: Third international conference ; C. Frasson, G. Gauthier, A. Lesgold (Eds.). – New York, NY : Springer, 1996. – P. 569-577.

8. Diagnostische Kompetenz: Theoretische Überlegungen zu einem zentralen Konstrukt der Lehrerbildung [Text] / C. V. Aufschnaiter, J. Cappell, G. Dübbelde, M. Ennemoser, J. Mayer, et al. // Zeitschrift für Pädagogik. – 2015. – Vol. 61, No. 5. – P. 738-758.

9. Open learner models in supporting self-regulated learning in higher education: A systematic literature review [Text] / D. Hooshyar et al. // Computers & Education. – 2020. – Vol. 154. – P. 103-108. – Article Id: 103878. DOI: /10.1016/j.compedu.2020.103878.

10. Almohammadi, K. Type-2 Fuzzy Logic based Systems for Adaptive Learning and Teaching within Intelligent E- Learning Environments [Text] : PhD in Computer Science. Thesis / K. Almohammadi. – University of Essex Colchester, UK, July 2016. – 184 p.

11. Stavrou, S. G. Common errors and misconceptions in mathematical proving by education undergraduates [Electronic resource] / S. G. Stavrou. – Access mode: https://www.researchgate.net/publication/261706000_Common_Errors_and_Misconceptions_in_Mathematical_Proving_by_Education_Undergraduates. – 15.08.2021.

12. Sharma, R. S. Fault Diagnosis Methods in Dynamic Systems: A Review [Text] / R. Sharma, L. Dewan, S. Chatterji // International Journal of Electronics and Electrical Engineering. – 2015. – Vol. 3, no. 6. – P. 465-471. DOI: 10.12720/ijeee.3.6.465-471.

13. Structural diagnosis method for computer programs developed by trainees [Text] / D. Gaydachuk, O. Havrylenko, J. P. Martínez Bastida, A. Chukhray // Proceedings of 15 th International Conference on ICT in Education, Research, and Industrial Applications. – Kherson, Ukraine, 2019. – P. 485-490.

14. Martínez Bastida, J. P. Developing a self-regulation environment in an open learning model with higher fidelity assessment [Text] / J. P. Martínez Bastida, O. Havrylenko, A. Chukhray // Information and Communication Technologies in Education, Research, and Industrial Applications. ICTERI 2017.

Communications in Computer and Information Science. – 2018. – Vol. 826, Springer, Cham. – P. 112-131. DOI: 10.1007/978-3-319-76168-8_6.

15. Chukhray, A. Proximate Objects Probabilistic Searching Method [Text] / A. Chukhray, O. Havrylenko // Integrated Computer Technologies in Mechanical Engineering. Advances in Intelligent Systems and Computing. – 2020. – Vol. 1113. – P. 219-227. DOI: 10.1007/978-3-030-37618-5_20.

16. Chukhray, A. The method of student's query analysis while intelligent computer tutoring in SQL [Text] / A. Chukhray, O. Havrylenko // Радіоелектронні і комп'ютерні системи. – 2021 – № 2. – С. 78-86. DOI: 10.32620/reks.2021.02.07.

17. Chukhray, A. The engineering skills training process modeling using dynamic Bayesian nets [Text] / A. Chukhray, O. Havrylenko // Радіоелектронні і комп'ютерні системи. – 2021 – № 2. – С. 87-96. DOI: 10.32620/reks.2021.02.08.

References (BSI)

1. Kulik, A. Rational intellectualization of aircraft control: Resources-saving safety improvement. *Green IT Engineering: Components, Networks and Systems Implementation*, 2017, pp. 173-192. DOI: 10.1007/978-3-319-55595-9_9.

2. Chukhray, A. *Metodologiya obucheniya algoritmam : monografiya* [Methodology for learning algorithms, monograph]. Kharkiv, National Aerospace University "KhAI" Publ., 2017. 336 p.

3. Somyürek, S. et al. How Do Students Perceive Their Own and Their Peers' Progress in E-Learning? *International Journal of Information and Learning Technology*, 2021, vol. 38, no. 1, pp. 49-74. DOI: 10.1108/IJILT-05-2020-0073.

4. Hooshyar, D., Ahmad, R. B., Yousefi, M., Fathi, M., Abdollahi, A., Horng, S. J., Lim, H. A solution-based intelligent tutoring system integrated with an online game-based formative assessment: development and evaluation. *Educational Technology Research and Development*, 2016, vol. 64, iss. 4, pp. 787-808. DOI: 10.1007/s11423-016-9433-x.

5. Hooshyar, D., Ahmad, R. B., Yousefi, M., Yusop, F. D., Horng, S.-J. A flowchart-based intelligent tutoring system for improving problem-solving skills of novice programmers. *Journal of Computer Assisted Learning*, 2015, vol. 31, iss. 1, pp. 345-361. DOI: 10.1111/jcal.12099.

6. Hooshyar, D., Ahmad, R. B., Shamshirband, S., Yousefi, M., Horng, S. J. A flowchart-based programming environment for improving problem solving skills of Cs minors in computer programming. *The Asian International Journal of Life Sciences*, 2015, vol. 24, no. 2, pp. 629-646.

7. Collins, J., Greer, J., Huang, S. Adaptive assessment using granularity hierarchies and Bayesian nets. In Frasson C., Gauthier G., Lesgold A. (Eds.), *Intelligent tutoring systems: Third international*

conference, New York, NY, Springer Publ., pp. 569-577.

8. Aufschnaiter, C. V., Cappell, J., Dübbelde, G., Ennemoser, M., Mayer, J., Stiensmeier-Pelster, J., et al. Diagnostische Kompetenz: Theoretische Überlegungen zu einem zentralen Konstrukt der Lehrerbildung, *Zeitschrift für Pädagogik*, 2015, vol. 61, no. 5, pp. 738-758.

9. Hooshyar, D. et al. Open learner models in supporting self-regulated learning in higher education: A systematic literature review. *Computers & Education,* 2020, vol. 154, pp. 103-108. Article Id: 103878. DOI: /10.1016/j.compedu.2020.103878.

10. Almohammadi, K. *Type-2 Fuzzy Logic based Systems for Adaptive Learning and Teaching within Intelligent E- Learning Environments*. PhD in Computer Science. Thesis. University of Essex, Colchester, UK, July 2016. 184 p.

11. Stavrou, S. G. *Common errors and misconceptions in mathematical proving by education undergraduates.* Available at: https://www.researchgate.net/publication/261706000_Common_Errors_and_Misconceptions_in_Mathematical_Proving_by_Education_Undergraduates (Accessed 15.08.2021).

12. Sharma, R., Dewan, L., Chatterji, S. Fault Diagnosis Methods in Dynamic Systems: A Review. *International Journal of Electronics and Electrical Engineering,* 2015, vol. 3, no. 6, pp. 465-471. DOI: 10.12720/ijeee.3.6.465-471.

13. Gaydachuk, D., Havrylenko, O., Martínez Bastida, J. P., Chukhray, A. Structural diagnosis method for computer programs developed by trainees. *Proceedings of 15 th International Conference on ICT in Education, Research, and Industrial Applications*, Kherson, Ukraine, 2019, pp. 485-490.

14. Martínez Bastida, J. P., Havrylenko, O., Chukhray, A. Developing a self-regulation environment in an open learning model with higher fidelity assessment. I*nformation and Communication Technologies in Education, Research, and Industrial Applications. ICTERI 2017. Communications in Computer and Information Science*, 2018, vol. 826, Springer, Cham, pp. 112-131. DOI: 10.1007/978-3-319-76168-8_6.

15. Chukhray, A., Havrylenko, O. Proximate objects probabilistic searching method. *Integrated Computer Technologies in Mechanical Engineering. Advances in Intelligent Systems and Computing.* Springer, Cham, 2020, vol. 1113, pp 219-227. DOI: 10.1007/978-3-030-37618-5_20.

16. Chukhray, A., Havrylenko, O. The method of student's query analysis while intelligent computer tutoring in SQL. *Radioelektronni i komp'uterni sistemi – Radioelectronic and computer systems,* 2021, vol. 2, pp. 78-86. DOI: 10.32620/reks.2021.02.07.

17. Chukhray, A., Havrylenko, O. The engineering skills training process modeling using dynamic Bayesian nets. *Radioelektronni i komp'uterni sistemi – Radioelectronic and computer systems*, 2021, vol. 2, pp. 87-96. DOI: 10.32620/reks.2021.02.08.

ДІАГНОСТИЧНЕ ЗАБЕЗПЕЧЕННЯ ІНТЕЛЕКТУАЛЬНОЇ СИСТЕМИ РЕПЕТИТОРА ДЛЯ НАВЧАННЯ НАВИЧОК ВИРІШЕННЯ АЛГЕБРАЇЧНИХ РІВНЯНЬ

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Незважаючи на всі плюси стандартного підходу до навчання студентів новим навичкам, ми все частіше стикаємося з проблемами, такими як: неможливість приділити однакову кількість уваги великій кількості студентів, опрацювати і однозначно виділити всі можливі проблеми і помилки, закрити прогалини в знаннях і т.д. Також всі ці складності стають ще більш актуальними з огляду на поточний стан справ в Світі і глобальної перехід на онлайн формат навчання. Як можливий варіант вирішення проблеми можна розглядати створення самостійних інтелектуальних систем, здатних взяти на себе частину навантаження викладачів і в автоматичному режимі брати участь в процесі навчання студентів. **Предметом** дослідження в цій статті є процес аналізу кроків для вирішення алгебраїчних рівнянь методом Лобачевського-Греффе-Данделі. **Метою** є моделювання процесу рішення алгебраїчних рівнянь і визначення всіх можливих кроків, складнощів і проблем у вирішенні таких завдань. **Завдання**: розробка системи, здатної проконтролювати виконання всіх необхідних кроків для даного рішення, визначити і класифікувати можливі помилки студента, в процесі оволодіння навичкою і пропрацювати їх. В процесі завдання були отримані наступні **результати**: було описано одне з можливих рішень для навчання навичкам вирішення n-статечного алгебраїчного рівняння методом Лобачевського-Греффе-Данделі. На основі сигнально-параметричного підходу до діагностики несправностей в динамічних системах створені математичні діагностичні моделі, які дозволяють виявляти класи помилок шляхом порівняння результатів розрахунків студента і результатів розрахунків системи. Наведено особливості і можливі складнощі застосування запропонованих діагностичних моделей. Була розроблена інтелектуальна самостійна система репетиторів і інтегрована в роботу на практичних заняттях з «Теорії автоматичного управління» студентами 3 курсу Національного аерокосмічного університету.

Ключові слова: інтелектуальна система репетитора; помилка студента; діагностична модель.

ДИАГНОСТИЧЕСКОЕ ОБЕСПЕЧЕНИЕ ИНТЕЛЛЕКТУАЛЬНОЙ СИСТЕМЫ РЕПЕТИТОРА ДЛЯ ОБУЧЕНИЯ НАВЫКАМ РЕШЕНИЯ АЛГЕБРАИЧЕСКИХ УРАВНЕНИЙ

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Несмотря на все плюсы стандартного подхода к обучению студентов новым навыкам, мы все чаще сталкиваемся с проблемами, такими как: невозможность уделить равное количество внимания большому количеству студентов, проработать и однозначно выделить все возможные проблемы и ошибки, закрыть пробелы в знаниях и т.д. Также все эти сложности становятся ещё более актуальными учитывая текущее положение вещей в мире и глобальной переход на онлайн формат обучения. Как возможный вариант решения проблемы можно рассматривать создание самостоятельных интеллектуальных систем, способных взять на себя часть нагрузки преподавателей и в автоматическом режиме участвовать в процессе обучения студентов. **Предметом** исследования в этой статье является процесс анализа шагов для решения алгебраических уравнений методом Лобачевского-Греффе-Данделена. **Целью** является моделирование процесса решения алгебраических уравнений и определение всех возможных шагов, сложностей и проблем в решении таких задач. **Задача**: разработка системы, способной проконтролировать исполнение всех необходимых шагов для данного решения, определить и классифицировать возможные ошибки студента, в процессе овладевания навыком и проработать их. В процессе задачи были получены следующие **результаты**: было описано одно из возможных решений для обучения навыкам решения n-степенного алгебраического уравнения методом Лобачевского-Греффе-Данделена. На основе сигнально-параметрического подхода к диагностике неисправностей в динамических системах созданы математические диагностические модели, которые позволяют обнаруживать классы ошибок путем сравнения результатов расчетов Стьюдента и результатов расчетов системы. Приведены особенности и возможные сложности применения предложенных диагностических моделей. Была разработана интеллектуальная самостоятельная система репетиторов и интегрирована в работу на практических занятиях по «Теории автоматического управления» студентами 3 курса Национального аэрокосмического университета.

Ключевые слова: интеллектуальная система репетитора; ошибка студента; диагностическая модель.

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