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Professional competence development when teaching computational informatics.

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Abstract
Bachelors and graduate students are offered in the course of teaching computational informatics, the ability to solve non-standard mathematical problems, which, as a rule, are not included in the content of teaching computational informatics. The article aimed to analyze the application effectiveness of non-standard mathematical problems in the course of teaching computational informatics, elaboration of constructive computational solution algorithms of inverse problems for differential equations, during which the bachelors and graduate students develop own professional competencies. The research conducted a review of previous literature on the topic. Formulation of the inverse problem for differential equations for the investigation of which the computational mathematics finite difference methods are applied, is presented. In the course of investigation, it was revealed that at elaborating the constructive computational algorithms of its solution, the bachelors and graduate students develop not only fundamental knowledge in the field of applied and computational mathematics, computational informatics methods, but also develop the professional competences, including computational thinking.

Key words: professional competence; computational informatics; computational mathematics methods; non-standard.

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1. Introduction

Contemporary development of industry, economy, agriculture and other human activity fields requires the practical implementation of innovative applied investigations (Zhafyarov, 2019). The most important implementation condition for such kind of projects is the availability of high-professional, self-motivated specialists, including in the field of applied and computational mathematics, computational informatics, who are capable to develop independently and embody competently the high-end, environmental protection technologies. Applied mathematics departments (either applied mathematics field or specialty) in conventional universities and higher technical educational institutions established in the late 1960s — early 1970s, currently train highly qualified specialists in the field of applied mathematics, computational mathematics, computational informatics. In the course of training students acquire fundamental knowledge on mathematical and functional analysis, algebra and geometry, ordinary differential equations and mathematical physics equations, computational information technology, computer technologies and other subject areas, acquire abilities and skills in investigation of applied problems through mathematical modelling and computational experiment. As a result, such graduates in their professional activities are able to elaborate correct mathematical models of the studied processes and apply effective methods typical for contemporary world science for their investigation with a view to acquire new knowledge related to the outward things (Bidaibekov, Kornilov, Kamalova & Akimzhan, 2015). The noted professional quality availability at such graduates vividly demonstrates their competence in the field of applied mathematics, computational mathematics, computational informatics and other subject areas.

The existing need for such competent specialists initiates the reform of academic institution applied mathematical education in the CIS countries. And nowadays, such work under the state body support is executed by the relevant Education and Science Ministries of the CIS countries. One of the results of such work is the development and introduction of the new generation state educational standards for higher professional education into the academic institution process, implementing the competency-based approach. In this regard, the results of the university graduate training are determined mainly through competencies.

Authors like Baydenko (2006) Bolotov, (2003), Raven (2006) Zhafyarov (2019), Kottaridi, Louloudi, Karkalakos (2019), Bergsmann, Schultes, Winter, Schober, Spiel (2019), Mirza et al., (2014), Cheetham, Chivers (1988), Abishev, Bidaibekov, Dalinger, & Knyazyev (2016), Bekoeva, Ambalova, Takhokhov (2018), Mayer (2019), Bidaybekov, Kamalova, Bostanov, Salgozha (2021) and other authors devoted their works to the various aspects of competence approach in education. The features of forming learners professional competence are considered in the studies of Zimnaya (2003), Tatury (2004), Vvedensky (2003), Zhafyarova (2016), Verbitsky, & Ilyazova (2011), Vinichenko, & Zayko (2018), Kennedy (2016) and other studies.

In particular, according to Bolotov and Serikov (2003), the competence-based approach does not put a premium on student awareness, but highlights their abilities to resolve problems arising in such situations as the understanding and explanation of real life phenomena, the mastery of modern equipment and technologies, human relations, in practical life when performing social roles as citizens, when it comes to legal rules and administrative arrangements, the choice of profession and assessment of their readiness for training in professional educational institutions, as well as in other situations.

Zhafyarov (2019) considers that the educational system based on the competence-based approach is effective and progressive. In his opinion, its usefulness consists in humanity as it warns students of the specific nature of today's quickly changing life.

When investigating the problem of development of student professional competencies, Vinichenko and Zayko (2018) identify the characteristics of development of student professional competencies within an active educational environment. The authors revealed the reasons for paradigm change in education from knowledge to competence. The features of interrelations within the "teacher – student" system are summarized.

Mayer (2019) investigates the problem of contradictions between the current long-standing practice of using an approach based on knowledge and skills in the educational process and the lack of a clear and precise continuity of the competence-based approach in relation to knowledge and skills. The author analyzes epistemological contradictions in the semantic "knowledge, skills, and competencies" series and identifies the hierarchy of interdependence of these concepts and, as a result, removes the contradiction between the current long-standing practice of using an approach based on knowledge and skills in the educational process and the competence-based approach.

The result of pedagogical education in this approach logic consists in professional competence. The content of teaching applied mathematics and computational informatics includes different mathematical problems. At the same time, there are non-standard mathematical problems, as far as their statement and solution methods are concerned, that are known as inverse problems.

Practical requirements often lead to the problems of determining the coefficients of differential equations (both ordinary and partial ones), of the right side, of initial conditions based on some known functionals of its solution. Such problems, unlike standard ones for differential equations, when the equation is set and we need to find its solution (direct problems), are known as inverse problems for differential equations — inverse in the cause-and-effect relation (restoration of unknown reasons for known consequences).

At the same time, "reasons" are concretized in the form of unknown coefficients, of the right side, of initial conditions. Functionals from the solution of a differential equation act as "consequences". Actually, the creation of a differential equation that adequately describes this or that physical phenomenon represents a solution to some problem that is naturally called "inverse problem". The researcher observes a phenomenon and tries to create an equation the solutions of which have properties under observation. In modern natural sciences they often deal with the following inverse problems: the general view of a differential equation is known, but the characteristic properties of an environment are unknown, they need to be determined based on the observable solutions of a differential equation.

The problem of student professional competence development is further elaborated in investigations conducted by Baidenko (2006), Bolotov, & Serikov (2003) Raven (2006), Zhafyarov (2019), Kottaridi, Louloudi, Karkalakos (2019), Bergsmann, et al., (2015), Zimnaya (2003), Tatura (2004), Vvedensky (2003), etc.

Teaching elaboration of computational solution algorithms of inverse problems for differential equations makes a definite contribution to developing the competence in the field of applied and computational mathematics, computational informatics that involves the issues related to algorithm mapping to the computational system architecture, application software for computational problems and methodology of process and phenomenon numerical simulation in the bachelors and graduate students of physical-mathematical and natural-scientific fields of education at higher educational institutions (Bidaibekov et al., 2014; Kornilov, Berkimbaev & Saparbekova, 2014; Bidaybekov et al, 2014; Kabanikhin et al., 2015; Kamalova et al., 2021; Kornilov, 2015; Kornilov 2005). Such non-standard mathematical problems are included in the content of the inverse problem theory for differential equations – one of the modern applied mathematics fields. Wide interest to inverse problems for differential equations is stipulated by their great practical importance.

This applied mathematics scientific field is developed in the investigations conducted Bidaibekov, et al., (2015), Kornilov, Berkimbaeva, & Saparbekova (2014), Bidaibekov, et al., (2014), Kornilov (2015), Levchenko, Kornilov, & Belikov (2009), Kornilov (2005) and many other scientists from the CIS and foreign countries.

1.1. Purpose of the study

The investigation purpose consists in analyzing the application effectiveness of non-standard mathematical problems in the course of teaching computational informatics– elaboration of computational solution algorithms of inverse problems for differential equations, during which the bachelors and graduate students develop own professional competencies.

2. Materials and methods.

2.1 Data collection method

This research analyzed data from previous literature in the field of teaching teachers computational informatics. The data was therefore secondary, and were collected from credible sources.

2.2 Analysis method

This study applied the inverse problem theory for differential equations – one of the modern applied mathematics fields in the analysis. The research however considers the methodology of previous research before suggesting a solution with this analysis method.

3. Results.

The investigation enables to draw logical conclusions regarding the positive influence of bachelor and graduate student teaching the elaboration of the computational solution algorithms of inverse problems for differential equations on their professional competence development. Application of computational mathematics and computational informatics methods enables to elaborate the constructive computational solution algorithms of inverse problems for differential equations, which are currently taught in the form of specialized courses in many CIS higher educational institutions for bachelors and graduate students that study in physical-mathematical and natural-scientific fields of education, noted above.

Let's present the formulation of one non-standard mathematical problem as an example — the inverse problem for a family of second order ordinary differential equations with an unknown coefficient, which is a part of the content of teaching bachelors and graduate students the computational informatics at the Institute of mathematics, physics and information technology of the Abai Kazakh National Pedagogical University. Bachelors and graduate students are suggested to find approximate solution to this inverse problem by means of computational mathematics finite difference methods. For brevity sake, we present the inverse problem formulation, the applied finite difference methods and general scheme for difference inverse problem investigation.

The inverse problem for the second order ordinary differential equation (Kornilov, 2005). The family of second order ordinary differential equations with an unknown coefficient $a(x)$ is considered:

$$y'' + a(x)\,y = 0, \quad y = y(x,\alpha), \quad y'' = \frac{d^2}{dx^2}y,\ x \in R,\ \alpha \in R, \tag{1}$$

with Cauchy data

$$y(\alpha,\alpha) = 1,\ y'(\alpha,\alpha) = 1,\ \alpha \in R \tag{2}$$

and additional information

$$y(x^*,\alpha) = \varphi(\alpha),\ x^* - const, \quad \alpha \in R \tag{3}$$

Inverse problem. From (1)– (3) to calculate the coefficient $a(x)$.

Bachelors and graduate students are suggested to elaborate constructive computational algorithm for the coefficient $a(x)$ determination using explicit and implicit difference scheme at the inverse problem approximation through finite difference ratios.

The case of explicit difference scheme. Students primarily replace the continuous domain of argument $x,\ \alpha$ variation with the net domain

$$\Omega_h = \left\{ (k,i) \middle| \ k = \overline{1,N},\ i = \overline{1,N},\ N = \frac{1}{h},\ h - шаг\ сетки,\ h << 1 \right\} \tag{4}$$

When using the explicit difference scheme, of course, the finite difference analogue of the difference ratios (1)– (3) takes on the form

$$\frac{v_{k+1}^i - 2v_k^i + v_{k-1}^i}{h^2} + \beta_k v_k^i = 0,\ k = \overline{1, N-1},\ i = \overline{0, N} \tag{5}$$

$$v_i^i = 1,\ i = \overline{0, N} \tag{6}$$

$$v_{i+1}^i = 1, i = \overline{0, N-1} \tag{7}$$

$$v_N^i = f_i,\ i = \overline{0, N}. \tag{8}$$

In (5)– (8) $v(k,i) = v_k^i,\ \beta(k) = \beta_k,\ f(i) = f_i,\ f_i = \varphi(\alpha_i),\ i = \overline{1,N}\ k,i = \overline{1,N}$ — net functions.

Bachelors and graduate students will have to calculate $\{\beta_k\}_{k=\overline{0,N}}$ from (5) – (8) as the approximate solution of the inverse problem (1) – (3).

Equality (5) is easily written down in the form of

$$v_k^i = (2 - h^2\beta_{k-1})v_{k-1}^i - v_{k-2}^i,\ k = \overline{1, N-1},\ i = \overline{0, N}. \tag{9}$$

If to put $k = N,\ i = N - 2$ in (9) and take into account additional information (8), one can calculate β_{N-1}:

$$\beta_{N-1} = \frac{1 - f_{N-2}}{h^2} = \frac{f_{N-1} - f_{N-2}}{h^2 \cdot 1} = \frac{\nabla f_{N-1}}{h^2 \cdot f_{N-1}}. \qquad (10)$$

In the future, simple mathematical calculations enable students to derive the following formula for finding the desired numerical sequence β_k:

$$\beta_k = \frac{\nabla f_k}{h^2 \sum\limits_{i=k}^{N-1} f_i}, \quad k = \overline{N-1, 1}. \qquad (11)$$

Due to the presentation brevity no further analysis of formula (11) is provided.

The case of implicit difference scheme. Using the implicit difference scheme, bachelors and graduate students build the finite difference analogue of difference ratios (1) – (3):

$$\frac{v_{k+1}^i - 2v_k^i + v_{k-1}^i}{h^2} + \beta_{k+1} v_{k+1}^i = 0,\ k = \overline{1, N-1},\ i = \overline{0, N}, \qquad (12)$$

$$v_i^i = 1,\ i = \overline{0, N}, \qquad (13)$$

$$v_{i+1}^i = v_{i-1}^i,\ i = \overline{0, N-1}, \qquad (14)$$

$$v_N^i = f_i,\ i = \overline{0, N}. \qquad (15)$$

They, as in the previous case, had to develop constructive computational algorithm for finding the approximate solution of differential inverse problem (12) – (15) – to calculate the numerical sequence $\{\beta_k\}_{k=\overline{0,N}}$.

The equality follows from (12)

$$v_{k-1}^i - 2v_k^i + v_{k+1}^i + h^2 \beta_{k+1} v_{k+1}^i = 0, \qquad (16)$$

from where, taking into account (13), (14) and $k = i$, it is easy to derive the expression linking β_i and v_i^{i-1}:

$$\beta_i = \frac{2(1 - v_i^{i-1})}{h^2 v_i^{i-1}},\ i = \overline{1, N}. \qquad (17)$$

Bachelors and graduate students notice that it is necessary to know the values only of v_i^{i-1} for finding β_i. This circumstance enables them to arrange sequentially the following step execution for calculating β_i.

Calculation β_N. To put $i = N$ in (16) and take into account (15):

$$\beta_N = \frac{2(1 - f_{N-1})}{h^2 f_{N-1}}. \qquad (18)$$

Calculation v_{N-1}^{N-2}. To put $k = N - 1,\ i = N - 2$ in (16) and take into account (13) – (15), (18):

$$v_{N-1}^{N-2} = \frac{1 + f_{N-2} + h^2 f_{N-2}}{2}. \quad (19)$$

Calculation β_{N-1}. To put $i = N - 1$ in (17) and take into account (19):

$$\beta_{N-1} = \frac{2(1 - v_{N-1}^{N-2})}{h^2 v_{N-1}^{N-2}}. \quad (20)$$

Their further similar actions lead to elaboration of the system of linear algebraic equations (SLAE) of the form

$$A_i Y_{i-1}^{i-2} = B_{i-2},\ i = N - 1, N - 2, \dots, 2. \quad (21)$$

In (21) A_i is a tridiagonal matrix

$$A_i = \begin{pmatrix} -2 & 1 & 0 & 0 & 0 & \dots\dots & & 0 & 0 \\ \theta_{N-1} & -2 & 1 & 0 & 0 & \dots\dots & & 0 & 0 \\ 0 & \theta_{N-2} & -2 & 1 & 0 & \dots\dots & & 0 & 0 \\ & & \dots\dots\dots\dots & & & & & & \\ & & \dots\dots\dots\dots & & & & & & \\ 0 & 0 & \dots\dots\dots & & 0 & 0 & \theta_{i+1} & -2 & 1 \\ 0 & 0 & \dots\dots\dots & & 0 & 0 & 0 & \theta_i & -2 \end{pmatrix},$$

$$Y_{i-1}^{i-2} = \left(v_{N-1}^{i-2},\ v_{N-2}^{i-2},\ v_{N-3}^{i-2}, \dots,\ v_{i}^{i-2},\ v_{i-1}^{i-2}\right)^T,$$

The first element of the column vector B_{i-1} is $\vartheta_N f_{i-2}$, the last is -1, and all other elements between them are zeros. Their number is equal to $p = N - 1 - i,\ i = \overline{N - 1, 2}$.

In the future, bachelors and graduate students will have to find SLAE solution (21). Finding the solutions like SLAE often turns out to be poorly conditioned problem, for example, when its matrix is ill-conditioned. This requires the choice of effective method for SLAE solution (see, for example Kabanikhin et al., 2015)

4.Discussion

The basic regulatory documents containing requirements to implementing the educational programs of bachelor and graduate student preparation in higher educational institutions are the State educational standards for the higher professional education approved by the Education and Science Ministries of the CIS countries. Such requirements include the characteristics of the field of education and professional activity, requirements to the educational program result development, to the educational program structure and other requirements. Requirements to the educational program structure include the list of studied training cycles, the content of training cycles, which comprise the basic and variable parts. The training cycle content includes educational subject areas, the presence of which is determined by the training professional direction (Bekoeva, Ambalova & Takhokhov, 2018).

The professional direction of bachelor and graduate student training in such fields of education as applied mathematics, applied physics, computational informatics and other fields of bachelor and graduate student education, determines the list of mathematical educational subject areas included in relevant educational programs based on which such training is conducted (Bergsmann, 2015).

These basic mathematical educational subject areas include: mathematical analysis, functional analysis, complex analysis, analytical geometry, algebra, optimization methods, probability theory and mathematical statistics, discrete mathematics and mathematical logic, integral equations, numerical methods and other mathematical educational subject areas. Fundamental knowledge on the above stated basic educational subject areas allows the bachelors and graduate students to master various computational mathematics methods which enable to derive and investigate the approximate solutions both for ordinary differential equations and partial differential equations, which also relate to the underlying mathematical educational subject areas (Verbitsky, 2011; Abishev et al., 2016).

Such mathematical methods include: approximate methods of ordinary differential equation solution (Taylor Series Method, Euler method, Runge–Kutta methods, methods of undetermined coefficients, double-sweep method, method of difference equations development for problems with discontinuous coefficients based on integral identity, etc.), mathematical physics variation methods (Ritz method, Galerkin method, least square method, etc.), method of mathematical physics stationary problem solution (conjugate gradient method, successive over-relaxation method, Chebyshev iterative method, splitting method, fast Fourier transform, cyclic reduction method, differential equation factorization, etc.), methods of mathematical physics non-stationary problem solution (stabilization method, predictor-corrector method, component-wise splitting method, etc.

5.Conclusions

Bachelors and graduate students operate with such fundamental computational mathematics notions at developing the constructive computational solution algorithms of inverse problems for differential equations, as discretization of continuous applied mathematics problem, net function interpolation, difference scheme convergence and stability, approximation error, computational error, types of computational mathematics problems and other notions related to computational mathematics. They acquire the abilities and skills of applying the information from the difference scheme theory, various methods of computational mathematics, which they were taught in training courses of mathematical, functional, vector analysis, analytical geometry, algebra, integral equations, numerical methods and other training courses, they realize the wide scope of its application in the applied mathematical problem investigations. Successful elaboration of computational algorithms for finding the approximate solutions of various inverse problems for differential equations is possible only if bachelors and graduate students have acquired fundamental knowledge in the field of applied and computational mathematics, computational informatics methods.

Bachelors and graduate students in the course of finding approximate solutions of inverse problems for differential equations are aware of the great role of computational mathematics, computational informatics in the applied problem investigations, acquire the abilities and skills to apply the methods of computational mathematics and computational informatics in solving the non-standard mathematical problems, make logical conclusions following the results of the found approximate solution of the inverse problem, develop professional competence, including — computational thinking.

To summarize, it is possible to draw general conclusions that inclusion in the content of the training computational informatics the non-standard mathematical problem, searching the solution of which involves elaboration of constructive computational algorithms, is expedient.

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