Mathematical model of successful research activities for technical university students

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Abstract. The main problem faced by the specialists of education management in determining the goals of regulation and development of students’ research activities is the imperfection of the evaluation mechanisms of scientific training at the university. The model includes the development of motivational, activity and evaluation components. This article focuses on the design of assessment component of students’ research activities. Assessment component of pedagogical system under consideration, i.e. in a technical university, includes the proposed results and the criterion indicators; mechanisms for diagnosis and improvement methods of students’ research activities. As projected results there may be: a model of high school graduate, the place of research competence in it, a model of research competence, a model of the scientific information environment of high school (resource potential). Depending on this, criteria indicators can serve as an increment of competencies in the composition and performance as well as resource potential of students research work. The purpose of the proposed research is to develop a mathematical model of research activities effectiveness of the technical students. This article discusses the possibility of using the conceptual and methodological apparatus of pedagogical qualimetry in studying the process of scientific training of students. In the article the possibilities of using pedagogical qualimetry terms and methodology in the study of students’ research process are observed. Diagnostics technique is offered to evaluate the efficiency of technical university students’ research efficiency. The result and index of students’ research system development are specified. As a result of the experiment, main components of students’ research competence and their weighting values are revealed. Linear mathematical model which allows diagnosing student’s research efficiency is constructed. Minimum (L_{min} = 33.75), maximum (L_{max} = 101.25) and threshold values of diagnostic assessment and their indicators are presented. This model is a basis for the test software which can be used further in practice.
1. Introduction

The main problem that educators face while determining the goals of regulation and development of student research activity is the imperfection of the evaluation mechanisms of scientific training at the university. Pedagogical monitoring of the scientific education system should include assessment of the students’ readiness to the research activities, effectiveness of their work, diagnostics for testing the level of research competences, evaluation of the psychological-pedagogical competence level that their scientific advisers possess, and the state of the scientific university environment, i.e. it should consider the student research activities as a multi-component system. The objective of this study is to develop a mathematical model of successful research activities for technical university students.

2. Qualimetric approach to science education of students

Due to the imperfection of the university scientific training evaluation mechanisms, it becomes evident that a qualitative approach is very important in diagnosing and predicting some elements of student research activities, as well as in assessing the readiness of students to this kind of work. Pedagogical qualimetry (qualitology education) along with the pedagogical control (monitoring, diagnostics) is one of the elements of education quality management [2, p. 39].

Diagnoses is usually considered as “the process and methods of determining the degree of development of personality traits, difficulties in learning, development, communication, career development, and also the efficiency of functioning and development of psychological systems, technologies, techniques, pedagogical projects [5, p. 197]”. The term qualimetry clearly defined as “quality measurement” was adopted in 1968 by a group of Russian scientists [1]. Initially, qualimetry meant the science of measuring and evaluating the quality of products. In the second half of the 20th century, the qualimetric approach gradually began to be used in relation to the educational process as well.

Today due to the extensive use of a competence-based approach and studies of education quality involving the assessment of this quality, the concept of the qualimetric approach is being actively developed in the national educational system (R.P. Arkaeva, G.S., Zhukova S.V. Komarova, Yu.A. Shikhov, O.F. Shikhova, etc.). The urgency of the qualimetric approach is confirmed by submitting a large number of dissertations on the subject, the relevant headings in the highly-ranked pedagogical journals (see, for example, the heading "Qualimetric approach in education" in the journal “Education and Science”), and also the expansion of the research vocabulary in this field of study.

According to A.I. Subetto, qualimetry in education is the science about the quality of education in all its diversity: the quality of the operation and development of educational systems; educational process, learners, teaching staff, etc. [9, p. 5].

National pedagogical qualimetry is regarded as the science which develops theoretical and applied problems of measuring and evaluating pedagogical objects, and as an area of pedagogical research carried out with the application of mathematical methods and aimed at the diagnostics of students and teacher’s personality and professional competences as well as the results of their learning and cognitive and pedagogical activities.

The main categories of the educational qualimetry scholarly apparatus is expert examination, qualimetric monitoring, testing and assessment, evaluation of the quality of graduates’ proficiency and professional training, Unified State Exam, education statistics, pedagogical analysis, pedagogical interpretation of the control activity results, etc. The main branches of the educational qualimetry are presented in detail in the monograph by G.S. Zhukova [4, pp. 37-38].

Thus, the qualimetric approach has two aspects: firstly, an assessment (an external to the student activity), i.e. a qualimetric technology of pedagogical measurements and, secondly, a qualimetric competence (an internal quality that is necessary for a teacher as well as for any other specialist in the modern world). Teachers consider that one of the basic conditions of using the qualimetric approach should be its integration with competency-based, andragogical, contextual, and acmeological approaches [6].
The assessment of process or object quality has a dual nature: it performs both regulatory and developmental function. Therefore, the use of the qualimetric technology in a pedagogical system of scientific training is of current importance. The proposed study will reveal not only the criteria for assessing the level of technical university student scientific training and the “weight” of the structural components of the research competence but also possible routes for developing students readiness to research activities [11].

3. An evaluative component of a system for student research activities

Student research activity (SRA) is a multi-level and multi-component process. A model for developing student research activities includes motivational and target-oriented, operational, and evaluative components. When designing the evaluative component of the student research activities system, it is necessary to answer the following questions:

1. How can the level of developing a culture of research in general as well as the individual research competences be measured? Is it important to identify a research competence or are the universal and professional competences that are well-known and fully described in pedagogical literature being developed during the scientific research?

From our point of view, there various technologies and evaluation criteria can be applied: interviewing and questioning the participants of the research activities (students) about the level of their competences increment while performing scientific activities, interviewing their scientific advisers and teachers. An employer’s evaluating and monitoring the graduate’s further scientific career (if a student has taken postgraduate courses, if he/she is able to use his/her scientific knowledge and skills in his/her professional activity, etc.) is a prospective line of research. In addition, such objective characteristics as publication activities, participation in scientific events, professional internship in Russia and abroad play a significant role in forming a criteria-based assessment.

2. Should the criteria for evaluating the student research competency differ depending on the level of higher education, can the criteria correspond with these levels?

We suppose that it is possible to speak about the basic (minimal), intermediate and advanced levels of development of various competences, skills and abilities. But the problem is that these skills can have different degrees of development, each scientific actor can possess a unique set of skills which does not depend on his/her level of higher education. On the other hand, the degree of development of certain skills must be documented for each level of higher education.

3. What are the measures that can be undertaken to correct the level of research competency development [10]?

The evaluative component of a pedagogical system for developing student research activities in a technical university includes:

1. A predicted result and criterion indicators.
2. Diagnostic mechanisms.
3. Ways of correction.

As for the predicted result, it may be presented in the form of:

- a model for a university graduate, with the research competence being its constituent,
- a model for a research competency,
- a model for scientific-information educational environment (resource potential).

Depending on this, increment of competences in the research competency and indicators of the research activities resource potential can be regarded as the criterion indicators [3, s. 198-210].

Indicators of developing research competency of technical students can be developed, and since they are pre-defined like requirements and standards they will be different for bachelor’s and master’s levels. At the same time, being an integrated personality trait, the research competency can be characterized by the different level of its development, from basic to advanced.

Basing on the conclusions for research competencies selection and content [7, pp. 12-13; 10, pp. 21-27; 12], we believe that to focus on the end results, possible technologies and indicators of the formation of research competence in a technical university it is necessary to distinguish the following
components:
1. Orientational: goal-setting, planning and forecasting, knowledge of the scientific research methodology.
2. Motivational: determining the value of research activities for the individual.
3. Activity (content, operational, technological), which includes research competence.
4. Reflexive.

These components are main in the structure of research competence. However, the research activities of students are also determined by the following components:
5. Cognitive, namely all the knowledge necessary for the formulation and solution of research tasks in professional activity; erudition, the ability to receive and assimilate new knowledge.
6. Informational and instrumental: modern information technologies awareness, the ability to collect and analyze information critically, the ability to apply knowledge in practice effectively.
7. Social and communicative: communicative competence, such as academic writing and presentation of a scientific text, foreign language competence, the ability to work in a team, to find a common language with an academic adviser and colleagues.

The structure of scientific activity of undergraduates, post-graduate students and scientists can also include:
8. Innovation and implementation component: implementation and commercialization of developments, economic laws awareness, etc.
9. Creative and heuristic component: fantasy, invention, freedom and independence of judgments.

Researchers B.I. Bedny and A. A. Mironos identified and ranked the most significant competencies of postgraduates. During the experiment, they interviewed 690 respondents from different cities of Russia. The method of selecting the relevant qualities is described in detail in the monograph of the authors [3, pp. 150-152]. Using the survey technique and methodology that we have developed for diagnosing student's readiness for research activities [11], we present the following structure of the research competence of a student with weighting coefficients obtained through expert analysis.

1. Motivational component. – 4.65
2. Orientation component. – 4.66
3. The activity component. – 4.04
4. Reflexive component. – 3.88
5. Cognitive component. – 4.35
6. Information component. – 4.45
7. Social and communicative component. – 3.68
8. Creative and heuristic component. – 4.04

Using the obtained weighting coefficients, we construct a mathematical model that allows us to evaluate the effectiveness of a student's research activities in the form of a linear function.

4. Mathematical model for effectiveness of student's research activities

\[ L = 4.65x_1 + 4.66x_2 + 4.04x_3 + 3.88x_4 + 4.35x_5 + 4.45x_6 + 3.68x_7 + 4.04x_8 \]  

(1)

where \( x_i = \{1;2;3…\} \) are the values of competence levels (each of the eight competencies is divided into at least three levels).

Analysis of this mathematical model allows to determine the minimum, threshold and maximum values of the diagnostic evaluation of the student's readiness for research activities, and to justify the values of the indicator for evaluating the effectiveness of student's research activities.
\[ \sum_{i=1}^{10} \gamma_i \]

\[ L_{\text{min}} = 10 \sum_{i=1}^{10} \gamma_i \]
is the minimum value of diagnostic evaluation.

\[ \sum_{i=1}^{10} \gamma_i \]

\[ L_{\text{th}} = 2 \]
is the threshold value (averaged) of the diagnostic evaluation of student readiness for research activities.

where \( \gamma_i \) is the weighting values of competences (components), presented in Table 1; coefficient 2 is a medium component level.

\[ \sum_{i=1}^{10} \gamma_i \]

\[ L_{\text{max}} = 3 \sum_{i=1}^{10} \gamma_i \]
is the maximum value of the diagnostic evaluation.

In numerical terms, it can be defined as follows:

\[ L_{\text{min}} = 33.75. \]
\[ L_{\text{max}} = 101.25. \]

We also introduce indicators for evaluating the effectiveness of student's research activities:

\[ L < 65 \] is below the average value for the effectiveness of student's research activities;

\[ 65 \leq L \geq 75 \] is the average value for the effectiveness of student's research activities;

\[ L > 75 \] is above the average value for the effectiveness of student's research activities.

This mathematical model is a tool for determining research activities effectiveness of technical university students. It is assumed that the result of the research will be developing a software, the implementation allowing to test the values of a linear function. Then, based on the threshold value and test results, it will be possible to diagnose the effectiveness of the student's research activities.

Further, considering the effectiveness evaluation of the student's research activities for each student as an independent random variable, and the mathematical expectation of the average arithmetic value of the sum of the evaluations, based on the Central Limit Theorem of probability calculation, as the arithmetic mean of the mathematical expectation of the evaluations, we obtain the numerical characteristics of the entire array of diagnosed values: mathematical expectation and mean square deviation. In this case, the "average total" random variable will be distributed according to the normal law. And, finally, having established the covariance – and such a relation takes place – between the magnitude of the efficiency and the number of students entering the magistracy and post-graduate studies, it is possible to predict this number and, accordingly, the rate of students’ selection.

**Conclusion**

1. Evaluation of the quality of a process or an object is dual: it fulfills both the controlling and the developing function. Therefore, the use of qualimetric technology in the pedagogical system of preparing students for research activities plays a formative role. On the other hand, qualimetric competence can be considered an integral part of the research competence of a student (postgraduate) of a technical university, and an analysis of the content of this competence is one of the prospects of our study.

2. We consider the following as the prospects of the study as:

   – development of soft mathematical models for evaluating the criterion indicators of the resource potential of the students research activities (human resources, finance, training, basic training of students) on the basis of macro criteria model of quality system evaluation for students research activities, which includes criteria for evaluating the system as the university's resource potential, the criteria for evaluating the process (management of the process), and the criteria for assessing the quality of the students' training (result);
– correlation of the evaluation of the effectiveness of student's research activities with the psychological and pedagogical competence of the scientific adviser;
– study of the possibilities of correction of the result obtained through the individual trajectories of scientific education of technical university.

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