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Research competencies of students direction "forestry" in the context of field practices

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Abstract

It is obvious that the forest ecosystem is the main topic of environmental issues for the world community, requiring high scientific and professional competencies and skills for effective solutions. Scientific competencies are especially required from specialists for whom forestry is interpreted through professional orientation and affiliation. Therefore, training students in the field of "forestry" with developed scientific research competencies is becoming the dominant model of modern specialized higher education. Students should not only be professionals in solving "forest" problems but also identify new problems and generate scientifically based solutions. Therefore, the generation and development of students' research competencies is a critical task for higher education, especially in areas that require an integrated approach to research activities, such as forestry. This paper proposes a linear mathematical model and an algorithmic model that describe the process of developing research competencies based on cognitive, procedural, and practical components. The linear mathematical model allows us to quantitatively assess the contribution of each component to the overall level of competence, identifying the process component as the most dominant. The experimental data show that the introduction of a practice-oriented methodology led to an increase in research competence of 35.3%, confirming the effectiveness of the model. The algorithmic model complements the linear analysis, allowing us to model the dynamics of competence development over time. The iterative approach demonstrates that the growth rate of competencies depends on their interrelation: insufficient development of the cognitive or procedural components acts as a resistance factor for overall progress. The algorithm of adaptive competence updating makes it possible to personalize educational strategies, predict student progress, and adjust curricula. The models considered can be used to optimize educational programs, provide individual support to students, and monitor the effectiveness of training. Future research may focus on integrating machine learning methods to predict individual competency development trajectories and take into account additional factors such as student motivation and external educational resources.

Keywords: Algorithmic model, Educational strategies, Forestry, Field practices, Linear model, Research competencies.

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1. Introduction

At the Munich Security Conference in February 2025, Vice President Tillman [1] "If American democracy can survive ten years of Greta Thunberg, you guys can survive a few months of Vance and Sanders [2]. "can survive ten Greta 's years Thunberg scolding, you guys can survive a few months of Phillips [3]. Setting aside the situation and personalities, this line reflects the real growing pressure of environmental movements and issues on national governments.

Here, we highlight two main environmental problems of the world community, which predominantly impose a high level of pressure on the national governments of many countries. These are water resources and forests. If we judge from the point of view of relevance, then these are the most urgent environmental problems of the planet and the world community.

These key problems are dynamic and are constantly becoming more complex. Complex problems require complex solutions. Accordingly, the ways, methods and practices for solving these problems have become more complex. In fact, a situation arises where standard professional skills and competencies are clearly insufficient and do not keep up with the high level of nonlinearity and multitasking of dominant environmental problems.

The only solution to this problem of increasing complexity of solutions is the generation and development of research skills for future specialists and professionals in the fields of forests and ecosystems. In this context, the development of students' research competencies is one of the key tasks of modern higher education, especially in applied disciplines such as forestry. In the context of increasing requirements for the scientific training of specialists, there is a need to develop and use formalized models that assess and predict the development of research skills. Modern educational programs require not only the transfer of knowledge but also the development of skills in independent data analysis, critical thinking, the use of scientific methods and the integration of practical skills into professional activities [4].

Research competencies are formed under the influence of three main components: cognitive (level of theoretical knowledge, fundamental training), procedural (ability to apply research methods, work with scientific literature and experimental data) and practical (ability to conduct experiments, interpret results and use them for decision-making) [5].

These components have complex relationships, and their dynamics require not only qualitative but also quantitative analysis.

This paper examines two models. A linear mathematical model that allows one to determine the contribution of each component to the overall level of competence. An algorithmic model that describes the dynamics of competence development over time and offers adaptive learning strategies.

The linear model allows us to obtain a quantitative assessment of the relationship between the components and the overall level of students' competencies. On the basis of the experimental data collected during the learning process, it is possible to determine the influence of cognitive, procedural and practical factors on the effectiveness of students' research activities. Analysis of the calculations reveals that the procedural component has the greatest influence, which is due to its importance in the application of knowledge in practice.

The algorithmic model, in turn, makes it possible to simulate the dynamics of competence formation. It takes into account the iterative learning process, within which students gradually develop research skills through successive stages of learning. The inclusion of adaptive mechanisms in the model makes it possible to predict the effectiveness of educational strategies and adjust teaching methods depending on the individual progress of students.

Thus, this study aims to develop mathematical and algorithmic tools that can be used to optimize the educational process, monitor learning effectiveness, and personalize educational trajectories. The results obtained will help universities and teachers develop adaptive training programs that allow for the most effective development of students' research competencies.

2. Literature Review

Thus, the development of students' research competencies in forestry is becoming a priority task of higher education in the context of global, regional and national environmental problems. Here, an important parallel question arises: what should be the educational methodology and technology for the formation and improvement of students' research skills and competencies? One of the key tasks of modern education is focused on sustainable development, scientifically based management of forest resources and the integration of innovative technologies in forestry. In this context, a comprehensive system of training specialists is needed, including a theoretical basis, practice-oriented training and the development of analytical skills through field research.

In the context of higher education, Abdimanapov, et al. [5] proposed a taxonomy of educational goals in which research competencies are related to the highest level of cognitive activity—the analysis, synthesis and evaluation of data. According to Bloom, et al. [6] students' active participation in research and fieldwork contributes to the development of critical thinking and problem-solving skills.

According to Piaget and Cook [7] the process of learning and developing students' scientific competencies correlates with direct interaction with a real ecological system. That is, directly with experimental, practical and field work and research in the educational system. This is fully consistent with Vygotsky, et al. [8] earlier theory Vygotsky and Cole [9] according to which the development of students' research competencies is most effective in the context of the immediate environment, that is, primarily in the practical sphere of learning.

Contemporary research indicates that research competencies are developed through an interdisciplinary approach that combines ecology, natural resource management, information technology, and experimental methods [10, 11]. In particular, Kolb [10] experiential learning model Kolb [10] demonstrates that optimal competence development requires four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation [12].

Thus, the listed theories and concepts confirm that the formation of research competencies is impossible without the active involvement of students in real research, especially in areas such as forestry, through educational practices. Here, a set of methods that structure and formalize educational technologies for the formation and development of research competencies is important. Therefore, modern educational programs require the integration of field research, work with real data and the use of mathematical modeling [13, 14].

One of the modern approaches is interpreted through project-based and problem-oriented learning (problem-based learning, PBL). This approach is actively used at the largest universities in the world (Harvard, Stanford) and includes the direct participation of students in real research projects in the forest ecosystem [15]. Students working in a PBL environment demonstrate a higher level of critical thinking and analytical skills [16]. Additionally, the use of GIS technologies and satellite monitoring in educational forestry programs contributes to the effective and efficient development of students' analytical skills [17]. With respect to digitalization, Franklin, et al. [14] show that combining traditional field methods with digital technologies improves learning effectiveness [14].

With respect to the formal approach, modern research in forest planning actively uses mathematical models to predict ecosystem changes [18]. Notably, students working with such formalized models master the methodology of scientific research more effectively and efficiently [19]. The integration of field practices and digital technologies increases the accuracy of forest ecosystem analysis. Ecosystem modeling based on field data generally increases the accuracy of forecasting [20]. Moreover, a number of studies confirm that field practices in forestry have a mobilizing and stimulating effect on the development of students' research competencies. In particular, field practices significantly increase the level of critical thinking [21]. Students who participate in field practices show increased and better analytical abilities [22, 23].

Thus, the integration of field practices into educational programs is a necessary condition for the training of specialists in the field of forestry.

Thus, on the basis of the literature data, the development of students' research competencies is impossible or ineffective without their active involvement in field practices and practical scientific projects. Moreover, modern educational programs should include a combination of field practices, digital technologies and mathematical modeling for the training of forestry specialists. Additionally, the development of procedural and practical competencies requires interactive teaching methods, including project-based learning and real ecosystem monitoring.

3. Materials and Methods

The organization of research work on the formation of scientific research competencies in forestry students was carried out in accordance with Table 1.

Table 1.
Organization of research work.

No.	Stage	Content
1	Organizational stage	Definition of experimental and control groups
2	Theoretical stage	Organization of seminars on data processing and interpretation. - Training in the basics of writing scientific reports and preparing presentations.
3	Practical stage	During the month, field trips to the nearest forests: - Study of the impact of climate change on woody plants. - Collection of cores and analysis of tree rings. - Primary analysis of the condition of trees.
4	Final stage	Assessment of the level of competence development. - Organization of a final scientific seminar to present the results.
5	Evaluation of the effectiveness of the method	Competency assessment criteria: - Critical level: lack of minimal knowledge and skills. - Basic level: basic understanding of the research process. - Advanced level: independent completion of research work.

No.	Stage	Content
		- Creative level: completing a full-fledged scientific project. Assessment methods: - Conducting tests to assess theoretical knowledge. - Analysis of students' reflective reports. - Expert assessment of the quality of research papers. Comparison of groups: Analysis of changes in the control and experimental groups before and after the experiment using statistical methods (t test for independent samples). Correlation analysis: Determining the relationship between students' activity and the level of their research competencies.

To develop students' research competencies, experimental and control groups were selected. An equal number of students in the groups was considered (the difference was no more than ±1). To ensure the reliability of the experiment, students from two higher education institutions were selected.

To develop research skills and professional competencies, the students in the experimental group were involved in field research. The students in the control group continued their studies via traditional methods. The number of students in the experimental and control groups is presented in Table 2.

Table 2.
Number of students in the experimental and control groups

Group	University	Well	Number of students
Control group	EKU named after Amanzholov [24] (CG 1)	2	22
	EKU named after Amanzholov [24] (CG 2)	3	21
	EKTU named after Ruzhansky, et al. [25] (CG 3)	2	15
	EKTU named after Ruzhansky, et al. [25] (CG 4)	3	6
	Total		64
Experimental group	EKU named after Amanzholov [24] (EG 1)	2	23
	EKU named after Amanzholov [24] (EG 2)	3	22
	EKTU named after Ruzhansky, et al. [25] (EG 3)	2	14
	EKTU named after Ruzhansky, et al. [25] (EG 4)	3	6
	Total		65

The development of the scientific research competencies of students majoring in forestry was carried out through the introduction of practice-oriented and theoretical methods, as well as the development of modern analytical approaches.

At the theoretical stage, the students in the experimental group were provided with theoretical knowledge, which was assessed during the completion of the assignments. Introductory lectures were given on the basics of dendrochronology and methods for studying the impact of climate change on woody plants. The topics and assignments of the theoretical stage are presented in Table 3.

Table 3.
Tasks for the theoretical stage.

No.	Chapter	Topics and Summary	Tasks
1	Introductory lectures	Dendrochronology and its importance in studying climate change. Structure of annual rings of woody plants and factors determining their size.	To study the structure of annual rings of woody plants and to form a hypothesis about the influence of climate change
		Research methodology. Selection of experimental plots and model trees. Collection of wood samples. Chamber processing of samples. Measurement of tree-ring width and cross - dating. Standardization of individual absolute growth series and creation of composite chronologies. Analysis of tree-ring chronologies	To determine the growth dynamics of trees by measuring the width of annual rings in several wood samples (cores).
		Preparation for field research: selection of sites, preparation of instruments, organization of work. Core sampling technique and rules for their storage	Prepare a plan for selecting a research site in your region.

No.	Chapter	Topics and Summary	Tasks
2	Seminars on data processing and interpretation	Collection, filtering and primary analysis of data Search and selection of necessary data from scientific articles: - Analysis of scientific articles from various sources. - Extraction of key ideas, data and research results from articles. - Filtering out unnecessary information and using data in accordance with the set goals. Application of statistical methods: - Correlation analysis. - Regression analysis. - Analysis of variance. Creating and interpreting graphs and charts: - Creating graphs and charts using programs (Excel, SPSS, R or Python). Interpretation of results: - Explaining research results in a scientific context. - Determining their significance for the topic under study	Analyze 5-7 articles on a specific topic and select the most important data. Present the analyzed data in the form of a graph or table. Interpret the results of statistical analysis and write a brief conclusion.
3	Training in the basics of writing scientific reports and preparing presentations	The structure of a scientific report: introduction, methods, results, discussion, conclusion. Scientific language style and presentation of evidence. Writing an abstract, keywords and creating the structure of the article. What is reviewing and its importance. Preparing slides for presentation: design, content and style of presentation.	Write a scientific report based on the research results. Prepare a presentation of 5-10 slides for a short report and defend it. Create and write a plan for a future article based on the results of your research.

This approach helps students develop skills in working with scientific articles and teaches them how to filter and analyze data.

During the practical stage, students collect dendrochronological materials in suburban forests every day for a month and process them. The work consists of five stages:

Wood sampling:

- A borer was used to determine the age of 10 wood samples (cores) from coniferous and deciduous trees. Pack them in accordance with the recommendations for transportation.
- Office processing of dendrochronological materials:
- Drying cores and preparing them for the measurement procedure.
- Measuring tree ring width and cross dating:
- Determination of the width of the rings and cross-dating of the samples.
- Standardization and construction of chronology:
- Calculation of growth indices via the TREND program.
- Creating a composite chronology in the ARSTAN program and constructing a chronology graph.
- Analysis of composite chronologies:
- Determination of the main statistical characteristics of the obtained chronology.
- Identification of years of minimum and maximum growth.
- Calculation and analysis of the correlation of growth indices with the main climate changes obtained from the nearest weather station.

Benefits of involving students in the study of tree dendrochronology:

Relevance of the topic:

Dendrochronology is an important area of research in the study of climate change and its impact on woody plants, as well as in forestry.

Scientific significance:

Analysis of tree rings allows us to study not only the age of trees but also the dynamics of their growth under the influence of environmental factors.

Practical application:

Students study methods for analyzing natural objects and master modern methods of working with data, including specialized software.

Skill development:

Working with cores and dendrochronological data helps develop analytical thinking and the ability to draw conclusions and develop recommendations for forest resource management.

Final stage:

All collected materials are used for writing reports and preparing future articles on the basis of the knowledge gained in the data processing and scientific report writing workshops.

4. Results

We propose the concept of an online complex of online tools for teaching chemistry on the basis of a systems approach.

The creation of a set of online tools for teaching chemistry via a systemic approach opens new opportunities for effectively mastering the material. Online resources allow one to personalize the learning process, take into account the learning characteristics of each student and improve practical skills. The integration of such tools requires careful preparation and development, but this makes teaching chemistry more exciting, accessible and effective.

4.1. Empirical Data

The level of formation of students' research competencies and the effectiveness of the methodology are determined through the assessment of the initial and final levels of their research competencies. The correspondence of diagnostic methods to the level of formation of research competencies was determined on the basis of psychometric methods, as shown in Table 4.

Table 4.
Methodology for assessing the level of development of students' research competencies.

Criteria	Indicators (High Level)	Diagnostic Methods
Motivational	Constant attention to problem solving; interest in scientific phenomena; independence in acquiring new knowledge	Modified test questionnaire of A. Mehrabian for measuring motivation for achievement.
Cognitive	Knowledge and skills necessary for carrying out research activities; knowledge of methods and techniques of research and project activities, research competencies.	Testing of mental development (diagnostics of intelligence)
Procedural	Application of research methodology; implementation of nonstandard approaches to solving research problems; planning, organizing and performing research activities based on one's own motivation	Expert evaluation of research and design products; results of competitions and conferences
Practical	Ability to collect, analyze and format data; skills in using research tools, equipment and software; ability to present research results clearly and understandably.	Control through the implementation of practical tasks; assessment of laboratory work results; special tests based on professional skills
Reflexive	Analysis and evaluation of research results; identification and definition of optimal approaches to research; assessment of the level of development	Self-assessment technique Budassi [26].

To determine the level of development of the research competence of students majoring in forestry at the initial assessment stage, the following research methods were used:

The motivational component was determined via a modified test questionnaire by Mehrabian [27] to measure students' motivation for achievement. According to Murray and Organization [28] students' motivation for achievement is characterized by the desire to achieve high results in work (study) activities, overcome obstacles, improve themselves, compete with other students, realize their talents and thereby increase self-esteem.

The achievement motivation test is designed to diagnose two stable general personality motives: the desire for success and the motivation to avoid failure. The test reveals which of these motives is dominant.

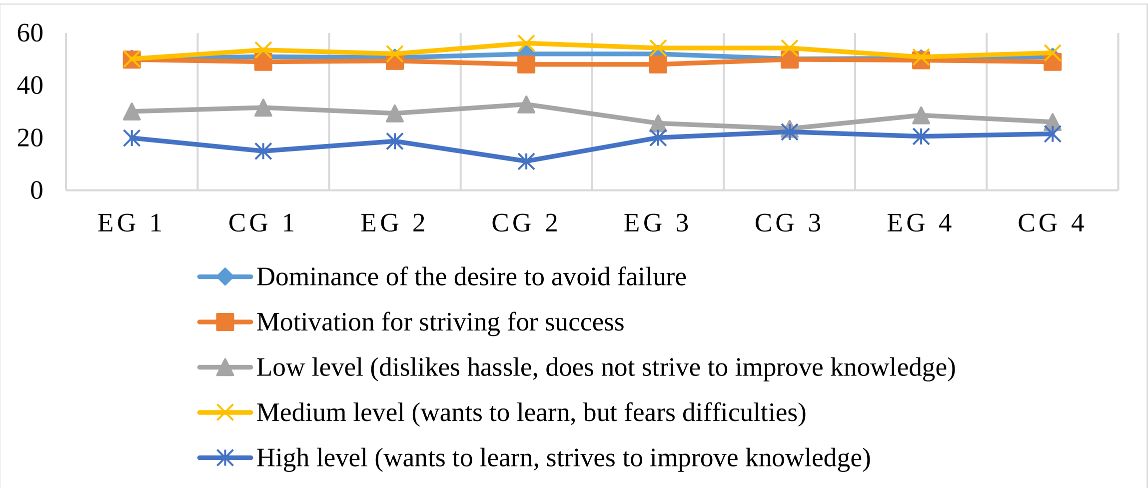

Figure 1.
Results of the initial level of the motivational component of the research competence of students in the control and experimental groups (%).

According to the data presented in Figure 1, in all the control and experimental groups, there is a predominance of the desire to avoid failure (more than 50%). The average difference between the control and experimental groups was 2.25%.

Compared with the control groups, the experimental groups were as follows:

- Low level of desire for learning is 1.5% lower;
- The average level of aspiration is 2.5% higher;
- High level of aspiration is 3% lower.

The control groups more often demonstrated a high tendency to avoid failure and a high interest in learning. Moreover, the students in the experimental groups had higher indicators of the average level of desire to learn, which may indicate a more balanced approach to learning.

The motive for achieving success among students in both groups is at a comparable level, and the difference is less than 1%, which indicates similar levels and approaches of students in both groups.

The cognitive component includes knowledge that allows students to conduct research. To diagnose the cognitive component, an adapted version of the school test of intellectual development developed by Borisova, et al. [29], Gurevich [30], Loginova, et al. [31], Kozlova, et al. [32] and other authors was used [33].

The adaptation of the methodology included changes in the content of the tasks, taking into account the level of knowledge and professional training of the students, while the main methodological principles of the test were retained:
Informativeness: testing the level of knowledge in various areas and general awareness.
Analogies: tasks to identify logical connections between concepts.
Classification: Grouping objects according to their characteristics.
Generalization: the ability to draw conclusions and identify patterns.
Number series: identifying patterns in number sequences.
Spatial thinking: operations with spatial structures and figures.

Table 5 presents the results of the initial level of formation of the cognitive component of the research competence of students in the control and experimental groups. The table shows the average scores and the percentage of correct answers of the students for each section.

Table 5.
Results of the initial level of formation of the cognitive component of research competence of students in the control and experimental groups (%).

	Section 1	**Section 2**	**Section 3**	**Section 4**	**Section 5**	**Section 6**	∑
Experimental group							
Average scores	14.7	15.5	15.6	15.6	14.3	14.8	90.3
Percentage of correct answers	73.5	77.5	78.0	78.0	71.5	74.0	75.42
Control group							
Average scores	14.1	15.9	16.5	16.8	14.5	13.3	91.1
Percentage of correct answers	70.5	79.5	82.5	84.0	72.5	66.5	75.92

The average scores of the experimental groups are 0.8% lower than those of the control groups, and the percentage of correct answers is approximately the same (75.92% in the control group and 75.42% in the experimental group). In the experimental groups, the percentage of correct answers in the six sections was more uniform, whereas significant fluctuations were observed in the control groups.

The procedural component includes the skills of planning research activities: defining goals, choosing methods, and structuring the stages of work.

The practical component reflects the ability of students to correctly carry out research in practice and achieve specific results. This component evaluates actions related to data collection, analysis, organization of the experiment and scientific presentation of the results.

Since the procedural and practical components are closely related, the students were asked "Determining the germination of seeds" to assess them. This task was aimed at assessing the use of research methods, the implementation of nonstandard approaches to solving problems, and the skills of planning, organizing and performing research activities.

To assess the process component, the students were asked to develop a study plan for examining the influence of various factors (e.g., temperature, humidity, and soil type) on seed germination. The plan included:

Determining the goal.
Description of work stages.
Selection and justification of methods.
Criteria for assessing the completion of the task:

Purpose of the study (0–3 points):

- Clear formulation of the goal.
- Relevance of the goal for forestry.

Research stages (0–3 points):

- Completeness (inclusion of the main stages: seed preparation, experimental setup, monitoring conditions, data processing).

- Sequence (logical order of work: from seed preparation to data analysis).
- Methods (0-3 points):
- Selection of methods suitable for seed germination testing (e.g., temperature control, selection of soil type, and statistical analysis).
- Validity of the chosen methods.

The results of the task allowed us to identify the level of students' skills related to the procedural component: the application of research methods, the implementation of nonstandard approaches, and the systematicity and efficiency of work performance. This task also demonstrated their interest in research activities and creative potential.

To assess the practical component, the students were asked to:

Conduct research.

Process data.

Present the results.

Evaluation criteria:

Performing the experiment (0--3 points):

- Ability to organize and perform an experiment accurately.
- Accuracy and consistency of the experimental data.

Data analysis (0-3 points):

- Correct processing of data and justification of conclusions.
- Visualization of results (graphs, tables).

Conclusions (0–3 points):

- Competent presentation of research results in a scientific style.
- Compliance of the obtained results with the purpose of the study.

The results of the study of the initial levels of the procedural and practical components of the students are presented in Figures 2 and 3, where key trends in the formation of research competencies are visible.

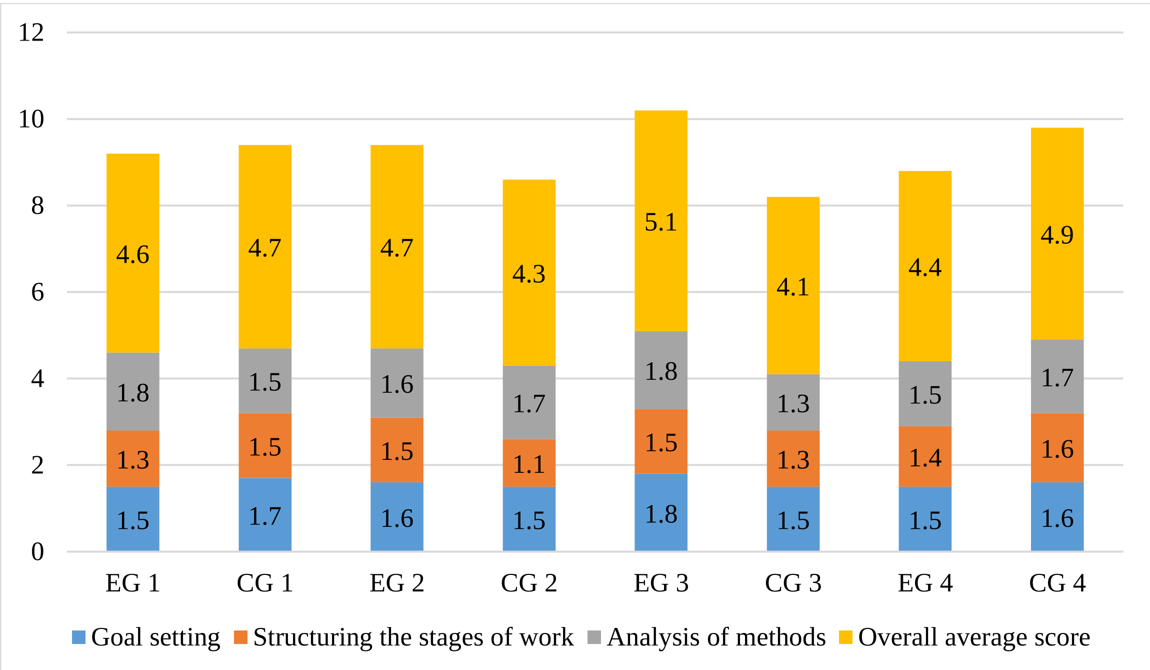

Figure 2.
Results of the initial level of the procedural component of the research competence of students in the control and experimental groups

The level of each component was determined by three different criteria. Each criterion was assessed on a scale ranging from 0 to 3 points, and the maximum score for the three criteria was 9.

When the procedural component was determined, the experimental groups scored an average of 4.7 points, whereas the control groups scored 4.5 points. This finding indicates that the students in both groups have insufficiently developed procedural skills.

Figure 3.
Results of the initial level of the practical component of research competence of students in the control and experimental groups.

In the practical component, instead of the maximum 9 points, the experimental groups scored an average of 3.6 points (40%), and the control groups scored 3.9 points (43.3%). The level of the practical component among the students in the experimental groups was 3.3% lower than that among the students in the control groups.

The results of both components show a low level of research competence among students and highlight the need for further work in this direction.

The reflective component reflects the ability of students to understand themselves and the environment in the process of completing educational research work, as well as to recognize themselves as subjects of research activities [34].

To determine the level of the reflexive component, the self-assessment method of Budassi [26] and Kondratieva, et al. [35] was used.

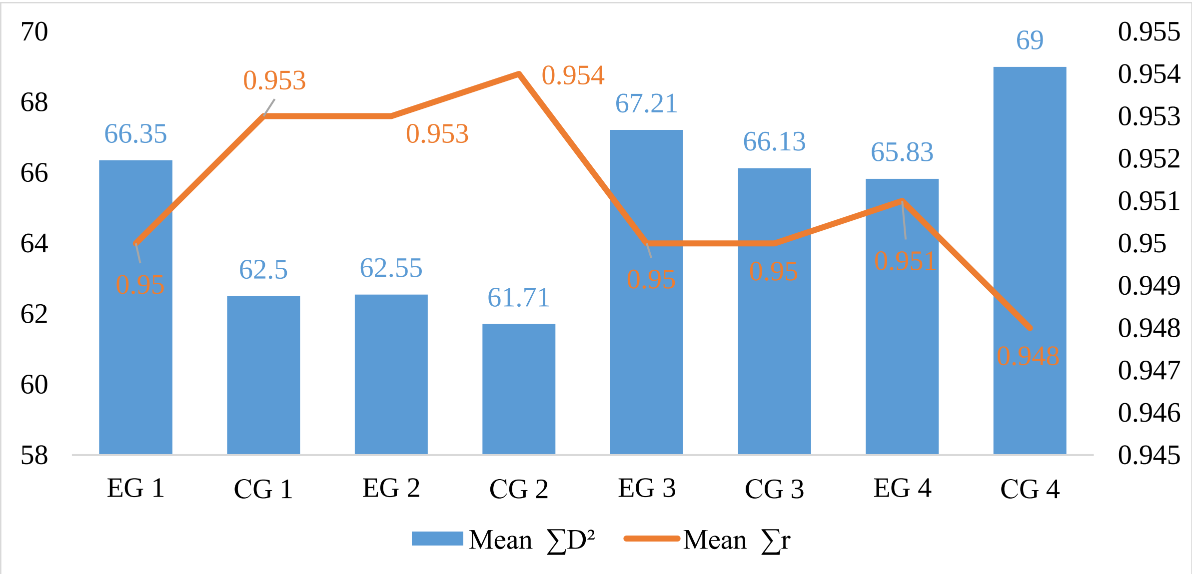

Figure 4.
Results of the initial level of the reflexive component of the research competence of students in the experimental and control groups

According to Figure 4 the values of ΣD^2 and r slightly differ between the experimental and control groups. This finding indicates that the initial level of reflection in both groups is approximately the same.

The range of ΣD^2 values from 65--69 in the experimental and control groups indicates a moderate discrepancy between the actual (d^2) and ideal (d^1) ranks. High ΣD^2 values close to 69 (e.g., in control group #4) reflect a large difference between how students perceive themselves and how they want to be.

The values of ΣD^2 and r show that the reflexive component in participants of both groups is formed at a low level and has potential for further development.

These differences indicate that group participants are, on average, aware of their strengths and weaknesses but require targeted work to further develop this competence.

The results of the experiment, conducted within the framework of the methodology for developing the scientific research competencies of students majoring in forestry, are comparatively presented in Figure 5.

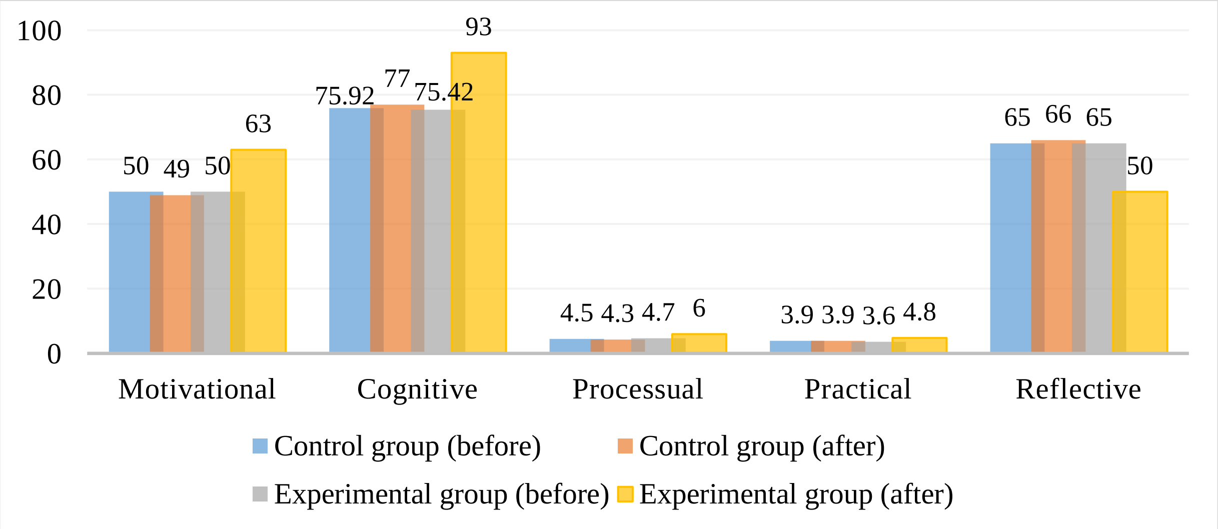

Figure 5.
Comparative indicators of the research competence of students in the experimental and control groups.

During the study, the effectiveness of the method was assessed by comparing the differences in the principal components between the control and experimental groups (1).

$$\text{Growth\%} = \frac{\text{Start value} - \text{End value}}{\text{Start value}} \times 100 \qquad (1)$$

The level of the motivational component in the experimental group (EG) increased by 26%, which indicates a significant increase in students' interest due to their active participation in practical research. In the CG, the level of motivation decreased by 2%, which indicates the low efficiency of the teaching methods used.

The level of the cognitive component in the EG increased by 23.3%, confirming a significant deepening of students' knowledge when completing research assignments. In the CG, this indicator increased by only 1.4%, which demonstrates the limited impact of standard methods.

The level of the procedural component in the EG increased by 27.7%, reflecting a significant improvement in students' skills due to their active participation in the research process. In the CG, the procedural component decreased by 2.2%, indicating insufficient methodological training.

The level of the practical component in the EG increased by 33.3%, which confirms the significant development of students' professional skills through their participation in practical work. In the CG, this indicator remained unchanged and amounted to 0%, which indicates the ineffectiveness of standard teaching methods in developing practical skills.

The level of the reflective component in the EG decreased by 23.1%, which was associated with a decrease in the ΣD^2 value and an improvement in the reflective abilities of the students. This indicates an increase in self-assessment skills (approaching ΣD^2 to 0 is considered a positive result). In the CG, the level of the reflective component increased by only 1.54%, which demonstrates the limitations of standard methods in developing reflection (2).

$$Medium_{efficiency} = \frac{\Sigma \ \text{growth of all components}}{\text{N}_{\text{component number}}} \qquad (2)$$

$$Medium_{efficiency} = \frac{26 + 23.3 + 27.7 + 33.3 - 23.1}{5} = 17.24\%$$

Differences between the experimental and control groups for each component (3):

$$\Delta = (\text{ET}_{\text{son.}} - \text{ET}_{\text{bass.}}) - (\text{BT}_{\text{son.}} - \text{BT}_{\text{bass.}}) \qquad (3)$$

The Δ values for each component differ between the experimental and control groups. These indicators reflect how much more effective the applied method was in the experimental group than in the control group.

$\Delta_{\text{int.}} = (63 - 50) - (49 - 50) = 13$

$\Delta_{cog.}$ = (93 - 75.42) - (77 - 75.92) = 15.08
$\Delta_{percent}$ = (6.0 - 4.7) - (4.4 - 4.5) = 1.4
$\Delta_{practice}$ = (4.8 - 3.6) - (3.9 - 3.9) = 1.2
$\Delta_{ref.}$ = (50 - 65) - (66-65) = -16

4.2. Formalized Model

Given the importance of an interdisciplinary approach, we propose a linear mathematical model of students' research competencies in the field of "forestry". The generation and development of students' research competencies is interpreted as a fairly complex process, including the development of cognitive, procedural and practical components. Standard and traditional linear models based on a weighted sum of these components allow us to predict and extrapolate the overall level of research competencies with a separate assessment of the contribution of each factor.

The analysis and synthesis of a mathematical model is based on experimental data, according to which, after field practice, there is an increase in the cognitive component by 29.4%, the procedural component by 45% and the practical component by 43%.

Accordingly, we set the goal of formulating a mathematical formalized model that allows us to identify quantitative dependencies between components and the overall level of competence, assess the contribution of each component to the generation of research competencies, and test the model on the basis of experimental data.

Let us assume that the total level of a student’s research competence is defined as a linear superposition of cognitive, procedural and practical components:

$$R = w(c)\,C + w\,(p)\,P + w(a)A + \varepsilon \qquad (4)$$

, where R is the total level of students’ research competencies,
C, P, and A are the cognitive, procedural, and practical components, respectively,
w (c), w (p), w (a) - contribution coefficients of each component,
ε is the random error of the model due to the individual characteristics of the students.

The superposition linear representation is obvious. Because the model should be convenient and practical for interpreting the results and calculations, an arbitrary increase in one of the components leads to an increase in research competencies, and each component makes an independent contribution to research competencies.

According to “*4.1. Empirical data*”, the experiment was conducted on a sample of student audiences, where the indicators of the control R c and experimental R e groups were compared.

In this case, the average values in the control group (C 0, P 0, A 0) were as follows: C 0 = 56.3, P 0 = 48.5 and A 0 = 52.1.

The corresponding increases in the experimental group can be interpreted as follows:

C = C 0 (1+0.294),
P = P 0 (1+0.45),
A = A 0 (1+0.43).

Taking this into account, the new values in the experimental group are presented as follows:

C = 56.3×1.294=72.8,
P =48.5×1.45=70.3,
A = 52.1×1.43=74.6.

We use correlation analysis to evaluate the weighting coefficients:

RC = 0.71,
RP = 0.78,
RA = 0.65.

, where RC, RP, and RA are correlations between R and C, R and P, and R and A, respectively.

Taking the sum of weights w(c) + w(p) + w(a) = 1, we write the solution in the following form:

$$w(c)\,0.71 + w(p)\,0.78 + w(a)\,0.65 = 1$$

As a result, taking into account relative increases, we obtain the following relationships:

w(c) = 0.30,
w(p) = 0.40,
w(a) = 0.30.

The numerical values of the coefficients indicate the key role of the procedural component in the development of students' research competencies. Theoretical knowledge is important, but its contribution is less than that of procedural skills.

Let us substitute the obtained values of the weighting coefficients into the indicators of the control and experimental groups:

$R_c = 0.30 \times 56.3 + 0.40 \times 48.5 + 0.30 \times 52.1 = 53.2$,
$R_e = 0.30 \times 72.8 + 0.40 \times 70.3 + 0.30 \times 74.6 = 72.0$.

Thus, we obtain the increase in research competence in an approximate numerical value:

$$\frac{\mathrm{Re} - \mathrm{Rc}}{\mathrm{Rc}} \times 100\% = \frac{72.0 - 53.2}{53.2} \times 100\% \approx 35.3\%.$$

Therefore, on the basis of the above, we can logically and adequately conclude that the considered model provides a sufficient level of prediction within the limits of the obtained experimental data. Moreover, the actual increase in competencies (≈35.3%) confirms that the linear dependence quite authentically explains most of the data variation.

The most powerful influence is exerted by the procedural component (P), which corresponds to the logic and assertion that field practices stimulate the generation and formation of research competencies in the experimental group.

The increase in research competencies in the experimental group was 35.3%, which confirms the effectiveness of field practices. The procedural component plays a dominant role ($w(p) = 0.40$), which indicates the importance of working with real research. The cognitive and practical components are equivalent (0.30 each), which emphasizes the need for a balance between theory and data analysis.

Thus, the proposed linear mathematical model of the research competencies of students in the field of “forestry” makes it possible to quantitatively (and qualitatively) assess the influence of cognitive, procedural and practical components on the overall level of competencies.

Thus, the linear model is an effective tool for analyzing the educational process and can be used to optimize educational methods in the field of forestry.

4.3. Algorithm Model

Let us assume that the formation of skills is implemented as a step-by-step and sequential process. Under this condition, we can define some contours of the algorithmic model:

- Stage-by-stage learning and the dependence of progress on previous levels of competence,
- The sequence of the development of cognitive, procedural and practical skills,
- The impact of feedback and adaptation of individual learning trajectories.

Then, the algorithmic model can be analyzed on the basis of the obtained experimental results. Within the framework, an increase in the cognitive component of 29.4%, the procedural component of 45%, and the practical component of 43% was recorded.

Let us consider algorithmic procedures for forming competencies through a sequence of steps. Accordingly, we introduce the following notations:

$C(t)$, $P(t)$, $A(t)$ - levels of cognitive, procedural and practical components at the temporal step t,
R_t - the general level of research competence at time step t,
ΔC_t, ΔP_t, and ΔA_t - the increase in each component per step ttt, which is determined by external factors;
$F(C,P,A)$ - competency update function,
τ is the threshold for successful transition to the next stage.

Thus, the integral process of developing students’ research competencies can be represented as an iterative algorithm, where students go through learning cycles, and their success depends on the level of competencies achieved.

At the initial stage, each student is assigned initial levels of competence, which are determined by the input parameters C_0, P_0 and A_0.

Similar values were obtained for the control group from the experiment: $C_0 = 56.3$, $P_0 = 48.5$, $A_0 = 52.1$.

At each time step t, the competency levels are upgraded according to the learning function:

$C_{t+1} = C_t + \Delta C_t$,
$P_{t+1} = P_t + \Delta P_t$,
$A_{t+1} = A_t + \Delta A_t$

In this case, the increase in research competencies ΔC_t, ΔP_t and ΔA_t is determined by two factors: external influence I_t, interpreted through the intensity of training, practice, research and the synergistic effect, expressing the mutual strengthening of components.

Thus, total modernization can be represented as follows:

$\Delta C_t = f_C(I_t) + \lambda_{CP} P_t + \lambda_{CA} A_t$,
$\Delta P_t = f_P(I_t) + \lambda_{PC} C_t + \lambda_{PA} A_t$,
$\Delta A_t = f_A(I_t) + \lambda_{AC} C_t + \lambda_{AP} P_t$.

The following notations are introduced here: $f_C(I_t)$, $f_P(I_t)$, and f_A are growth functions that depend on the volume of educational and research activities, and λ_{CP}, λ_{CA}, and λ_{PA} are synergistic effect coefficients.

After each update, the overall level of research competence is calculated:

$$R_t = w_C C_t + w_P P_t + w_A A_t$$

If $R_t \geq \tau$, the student moves on to the next stage of learning, where the tasks become more complex. If $R_t < \tau$, the learning strategy is adapted. In particular, the intensity of I_t increases, and the emphasis on weaknesses is adjusted.

In general, this cycle is reproduced until a steady state is reached, in which

$$|R_{t+1} - R_t| < \varepsilon.$$

That is, when the growth of competencies slows, the optimal level of training is reached.

In the experimental group, the increases were

$\Delta C=29.4\%$,
$\Delta P=45\%$,
$\Delta A=43\%$.

Let us substitute the percentage data into the update:

$C_e = C_0(1+0.294) = 72.8$,
$P_e = P_0(1+0.45) = 70.3$,
$A_e = A_0(1+0.43) = 74.6$.

Using weights $w_C = 0.30$, $w_P = 0.40$ and $w_A = 0.30$, we finally obtain:

$R_c = 0.30\times56.3 + 0.40\times48.5 + 0.30\times52.1 = 53.2$,
$R_e = 0.30\times72.8 + 0.40\times70.3 + 0.30\times74.6 = 72.0$.

In this case, the increase in research competencies is interpreted as

$$G = \frac{Re - Rc}{Rc} \times 100\% = \frac{72.0 - 53.2}{53.2} \times 100\% \approx 35.3\%.$$

Thus, with iterative modeling that takes into account the synergistic effect, with an increase in the cognitive component of 10%, the growth of the procedural component accelerates by 4%, and with an increase in the procedural component of 15%, the growth of the practical component accelerates by 5%.

This circumstance confirms that integrated training produces better results than separate development of research and general educational components.

Thus, the algorithmic model confirms the experimental data and allows modeling of the dynamics of competence formation. The effect of interactions is quite significant: procedural skills are the most critical, since their increase directly and clearly accelerates the development of other components. In the context of dynamic adaptation, students with insufficient competencies can receive individual educational trajectories. In terms of applicability, the model can be used in adaptive learning systems, where the growth of competencies is monitored and educational strategies are adjusted.

On the basis of the above, we can conclude that the algorithmic model of students' research competencies can become not only a tool for quantitative analysis but also a basis for optimizing the educational process in the field of forestry in the context of the scientific content and scientific culture of students.

5. Discussion

Thus, the experimental data confirm the effectiveness of the practice-oriented methodology. At the same time, educational and training processing related to the ecological need to generate and activate student research skills is ineffective without an interdisciplinary approach. In particular, without the development of a formal apparatus that allows monitoring, the process of developing the skills of scientific workers in students majoring in forestry should be optimized and managed.

In this work, we postulated two models describing the process of the formation of these competencies: a linear mathematical model and an algorithmic model.

On the basis of a linear mathematical model, the quantitative contribution of cognitive, procedural and practical components to the integral level of students' research competencies was assessed.

Notably, the procedural component is the most significant component in the generation and formation of scientific and research competencies in students. This circumstance, in fact, confirms the obvious importance of the practical application of knowledge and skills. The cognitive and practical components have identical contributions to competencies. It logically follows that educational and training processing requires a balanced approach to the generation and activation of research competencies in an interdisciplinary context.

In general, the linear model can be authentically and adequately adapted for a quick assessment of the current level of students' research competencies but may not consider the dynamics of their development.

The algorithmic model significantly complements the linear formal analysis. The actual possibility of analyzing the dynamic process of the formation of students' research competencies over time is as follows. In the context of algorithmics, it is shown that research competencies develop iteratively. Moreover, iterative growth depends not only on the intensity of educational and training processing but also on the synergy between the components. With a deficit of cognitive knowledge or procedural skills, further progress in competencies slows down. This circumstance implies the need for an integrated approach to educational and training processing. focused on research competence. which indicates the importance of an integrated approach in training.

In general, the logical model makes it possible to forecast the formation and development of student research competencies and correct the trajectory of their development. "Weak links" in educational processing can also be analyzed, and, on the basis of the analysis, methods and ways of strengthening them can be synthesized.

Therefore, the mathematical and algorithmic models can be used under the following circumstances:

1. To assess the quality of educational programs, the linear model helps determine which components require increased attention.

2. For the individual support of students, the algorithmic model allows us to predict their progress and adapt educational strategies in a timely manner.

3. To optimize curricula, models can be used in the development of new educational courses, ensuring an optimal balance between theory, methodology and practice.

4. To monitor the effectiveness of teaching, analysis of the dynamics of the growth of competencies can serve as a tool for adjusting teaching methods.

Despite the high accuracy of the proposed models, further research may include the following:

1. Integrating machine learning models to predict individual student development trajectories.

2. Expanding the algorithmic model to consider the influence of external factors (e.g., student engagement, motivation, digital learning tools).

3. Application of models in different educational areas to identify universal patterns in the formation of research competencies.

The linear mathematical model and algorithmic model considered demonstrate that students' research competencies are formed both through the systematic accumulation of knowledge and through its practical application and interaction between components. The optimization of the educational process while considering these models will improve the quality of training for specialists, which is especially important in such applied disciplines as forestry.

The introduction of such models into the educational environment can become a key tool for improving the higher education system in the context of generating and developing student research competencies.

6. Conclusion

Thus, the work contains experimental and theoretical studies of effective mechanisms for intensifying the research competencies of students majoring in forestry. An interdisciplinary approach based on comparative analysis and cross-analysis of educational models, mathematical modeling, and processing of empirical data is used. Additionally, for the first time, a nonlinear mathematical model has been created that describes students' research competencies in the context of field research and practical classes. The model interprets, analyzes, and synthesizes motivational, cognitive, procedural, practical, and reflexive components of students' research competencies. On the basis of experimental data, the weighting coefficients for the equations of the mathematical model are calculated and determined for the first time. The developed mathematical model demonstrates that the intensity and quality of practical research have a key influence on the formation of competencies and that their development occurs nonlinearly and requires dynamic management of the educational process. Field practices have the greatest impact on procedural and practical competencies, with growth rates of up to 33.3% and 27.7%, respectively. The saturation effect was confirmed: upon reaching a certain level of training, further development of competencies slows down, which requires more complex research tasks and the integration of new educational technologies. The optimal level of field research was determined: 2 to 3 hours a day are sufficient for the sustainable growth of competencies, whereas with a decrease in practical activity, the dynamics of their development slows. The developed approach allows us to optimize and adapt educational programs, forming the development of students' research competencies depending on the quantity and quality of field practices. The obtained results can be directly and clearly applied to the methods of training specialists in the fields of forestry, ecology, bioresources, and nature management. The development of the research competencies of students in the field of forestry is impossible without the integration of field research, analytical work, and a reflexive understanding of data.

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