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Scientific principles of information-activity-based learning in university natural science disciplines

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Abstract

The article is dedicated to the analysis and conclusions of a research project conducted by the physics departments of Kazakhstani universities from 2018 to 2025. The outcomes of the study were driven by the need to develop specific methodologies for organizing practical sessions, laboratory work, independent study (ISR), and independent study with instructor support (ISRS), all oriented toward a training model aimed at creating a learning environment that not only fosters the development of subject-related competencies but also cultivates the personal qualities of future professionals. In this context, the department developed methodological foundations for teaching the physics course based on a professional activity model across various fields. The experience of integrating informational and activity-based approaches in this work relies on both the recognition of the need for the informatization of education and the activity-based approach to learning. While informatization focuses on incorporating information and communication technologies into the educational process, the activity-based approach empowers students to develop their own potential by finding individual pathways to knowledge and progressing independently through educational stages. This is possible only with appropriately structured educational activities. This study demonstrates that the formation and assimilation of fundamental concepts and laws of physics by students can be achieved through specially organized informational and cognitive activities. The logic behind organizing such activities during instruction is interdependent with the structure and content of the learning material. The methods used to study physical laws, their comprehension, and the acquisition of problem-solving techniques become methods of informational and cognitive activity for students.

Keywords: Information-activity-based learning, Professional competencies, Professional self-determination, Student, University.

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1. Introduction

It is well known that effective management of the learning process involves the formulation of educational goals, the development and organization of the learning environment, the collection of information on the state of learning, and the integration of corrective measures into the educational process [1-3]. However, the entire learning process must also be oriented toward the development of the personal qualities of future professionals that are essential as they enter the workforce. In this regard, the primary and most important aspect of Information-Activity-Based Learning (IABL) is the development of personal abilities and traits, including readiness for ongoing self-determination (particularly professional), professional orientation, professionally oriented competencies, and professionally significant qualities. Therefore, training in natural science disciplines should be based on a model of professional activity in a given field [4-7].

In line with this, models of training were developed for various specialties such as thermal power engineering, radio engineering, and telecommunications. The methodology for developing these models is detailed in prior works [8-14]. This approach made it possible to structure IABL in physics across three levels:

- Level one involves creating a model of professional activity, based on which the learning objectives are defined. These are presented to students through the syllabus in the form of classroom and extracurricular workload, formats, timelines, assessment events, elements of the modular course program, and the academic work schedule.
- Level two provides students with all necessary learning materials through lectures, textbooks, and study guides.
- Level three encompasses organizsational and methodological support in the form of manuals and guides. individual learning paths are revealed through methodological instructions for practical and laboratory work, calculation and graphical tasks, and isrs assignments, enabling students to master specific knowledge components.

2. Methodology

Currently, the department is developing an electronic information model that effectively reflects the content of training within the discipline. It includes text and hypertext, structured instructional content, a system of self-assessment tests, as well as teaching guides and manuals [15, 16].

Figure 1 illustrates the structure of the information-educational environment, which integrates didactic methods, forms, and tools for developing readiness for professional activity, pedagogical control mechanisms, the identification of correlations between academic success (as expressed through competency formation and personal qualities), and subsequent adjustments to the learning environment.

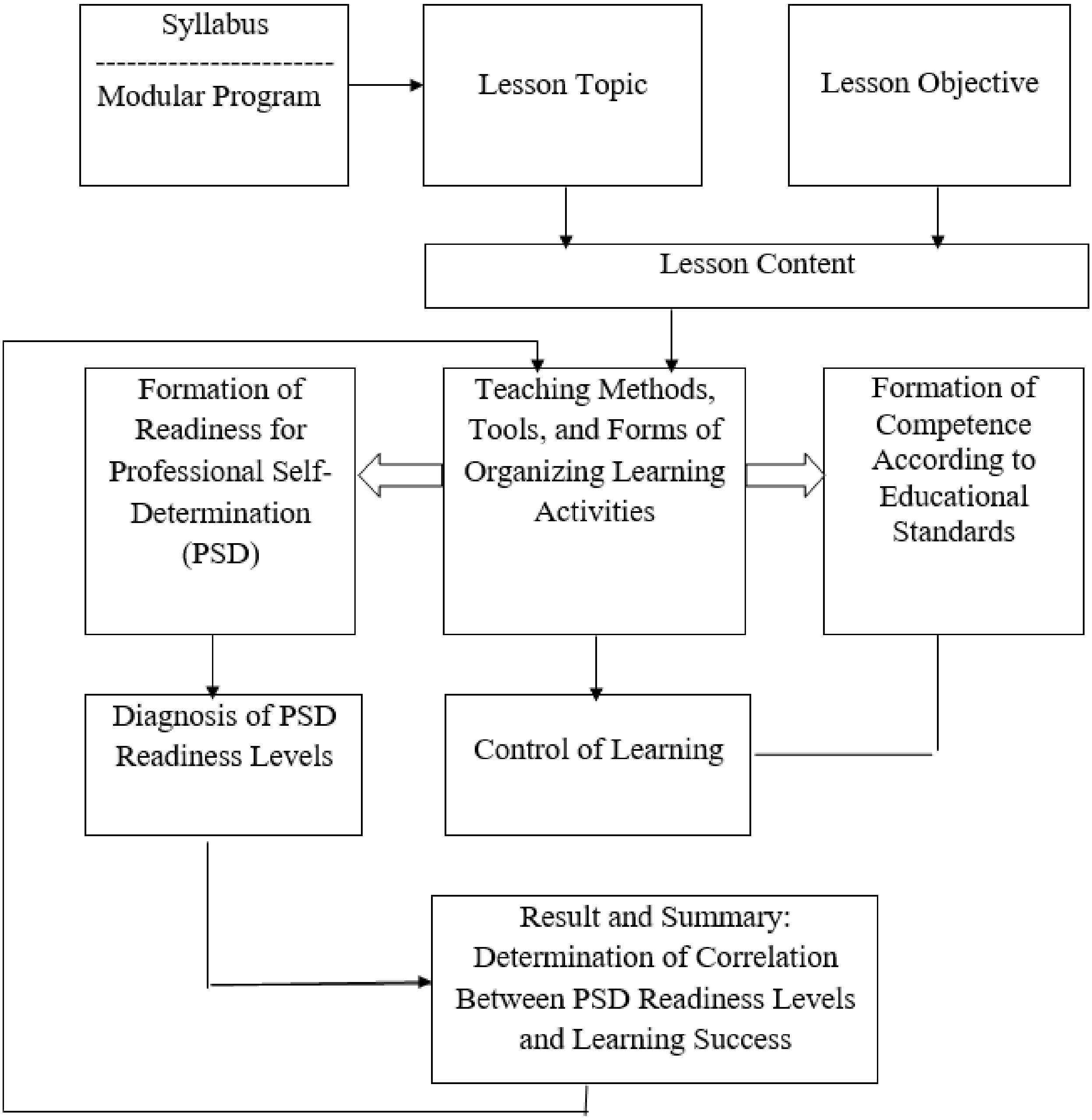

Figure 1.
Diagram of the interconnections between components of the information and educational environment for developing student readiness for professional self-determination (PSD).

Table 1 presents a detailed breakdown of the components of the educational environment using the topic «Electromagnetic Induction: Fundamentals of Maxwell's Theory» as an example.

Table 1.
Breakdown of the components of the educational environment using the topic «Electromagnetic Induction: Fundamentals of Maxwell's Theory» as an example.

Topic	**Phenomenon of Electromagnetic Induction. Fundamentals of Maxwell's Theory**
Objective of the Lesson	To understand the physical meaning of the phenomenon of electromagnetic induction and its consequences. Maxwell's system of equations is the theoretical basis of electromagnetic phenomena.
Lesson Content	The basic law of electromagnetic induction. Faraday's Law and Lenz's Rule. Inductance, the phenomenon of self-induction. Switching and breaking surge currents. Energy and energy density of the magnetic field. Vortex field, displacement current. Maxwell's system of equations. Relativity of electric and magnetic fields.
Methods and Forms	Traditional teaching methods, heuristic, problem-based, and research methods. Practical and laboratory sessions, independent student work (ISW), student project presentations, conferences, and discussions.
Instructional Support	Lecture notes on the topic in both electronic and paper formats, slides, methodological manuals and guidelines, self-study questions and tests. Course projects (CP), theoretical and practical individual assignments, work with hypertexts, slides, self-study and self-assessment using texts.
Means for Forming Competencies and Levels of Readiness for Professional Self-Determination (PSD)	Competencies and Readiness Levels for PSD: Ongoing assessment of task completion, summarizing results of CP and lab work, midterm assessments, diagnostic tests, and student surveys.
Control of Educational Activities and Diagnosis of PSD Levels	Formation of competencies on the topic. Formation of levels of readiness for professional self-determination.
Result and Summary	Determining the correlation between levels of readiness for professional self-determination and learning success, as expressed through competencies.

In turn, professional competencies include a set of interrelated individual personality traits (knowledge, skills, abilities, methods of activity, and capabilities) that determine the effectiveness of solving tasks arising in the process of productive professional activity and represent a core component of the information and educational environment (IEE) [17-22].

Competence, in this context, refers to a set of standards that clearly define what a student needs in order to perform their future job in the best possible way [23-28].

3. Results and Discussion

In this regard, from 2018 to 2025, we conducted an experimental pedagogical study based on the information and educational environment aimed at developing competencies and readiness for PSD. The study was carried out at Kazakhstani universities as a diagnostic (ascertaining) experiment. The purpose of this diagnostic experiment was to identify the levels of competency development and readiness for PSD among bachelor's students.

The results of the study on professional competencies, obtained during the diagnostic phase of the experiment, confirmed our assumption that the absence of a specially organized information and educational environment in the early years of study negatively impacts the development of student competencies. For example, 62.6% of first-year and 36.7% of second-year students demonstrated a low level of professionally oriented competence; the medium level was observed in 32.8% and 35.9%, respectively.

The formative experiment was conducted at the Institute of Green Technologies. The total number of students in the experimental group was 121. The aim of the formative experiment was to develop students' knowledge, skills, behavioral patterns - in short, competencies. During the formative experiment, diagnostic assessments were conducted; based on the analysis of the collected data, plans for corrective measures and interventions were developed. The formative experiment was carried out in several stages:

1. Orientation Stage – focused on forming basic indicators of the motivational component, professional orientation, and cognitive interest among students, and orienting them toward the content of theoretical knowledge, intellectual skills, and self-education practices.
2. Formative Stage – focused on developing the core indicators of the content and procedural components, setting students up for systematic acquisition of knowledge, skills, and abilities.
3. Developmental Stage – emphasized improving skills and activities associated with the operational component through progressively more complex tasks.
4. Integrative Stage – aimed at forming medium and high levels of competence among students. Active surveys, direct and indirect testing, purposeful observation, and expert evaluation analysis were conducted.

The results of the experiment revealed a general trend in both experimental and control groups: as students progressed through the stages of competence development, their personal qualities improved. However, the nature of the dynamics varied between the experimental and control groups. According to the data presented in Table 2, the number of students with a low level of competence in the experimental groups decreased significantly, from 64.5% to 16.5% (a reduction of 48%), while in the control groups, the reduction was only 23%. At the same time, the number of students with a sufficient level of competence in the experimental groups increased from 5.3% to 39.7% (an increase of 34%), and only by 21% in the control groups. Additionally, there was a noticeable increase in the number of students with a high level of competence in the experimental groups compared to the control groups.

Table 2.
Levels of bachelor's competence formation at different stages of the experimental pedagogical study based on the information and educational environment (in %).

Levels of development of students' TC	**Experimental groups**					**Control groups**	
	Phase, %						
	Initial	**I**	**II**	**III**	**IV**	**Initial**	**IV**
low	64.5	55	43.1	32.9	16.5	63.5	40
average	34.2	37.8	43.8	40.3	38.9	31.3	36.3
sufficient	5.3	9.5	14.5	26.8	39.7	6.4	27.6
high	-	-	-	-	4.9	-	1.3

The results of the assessment make it possible to observe a positive trend in the development of the targeted quality (see Figure 2).

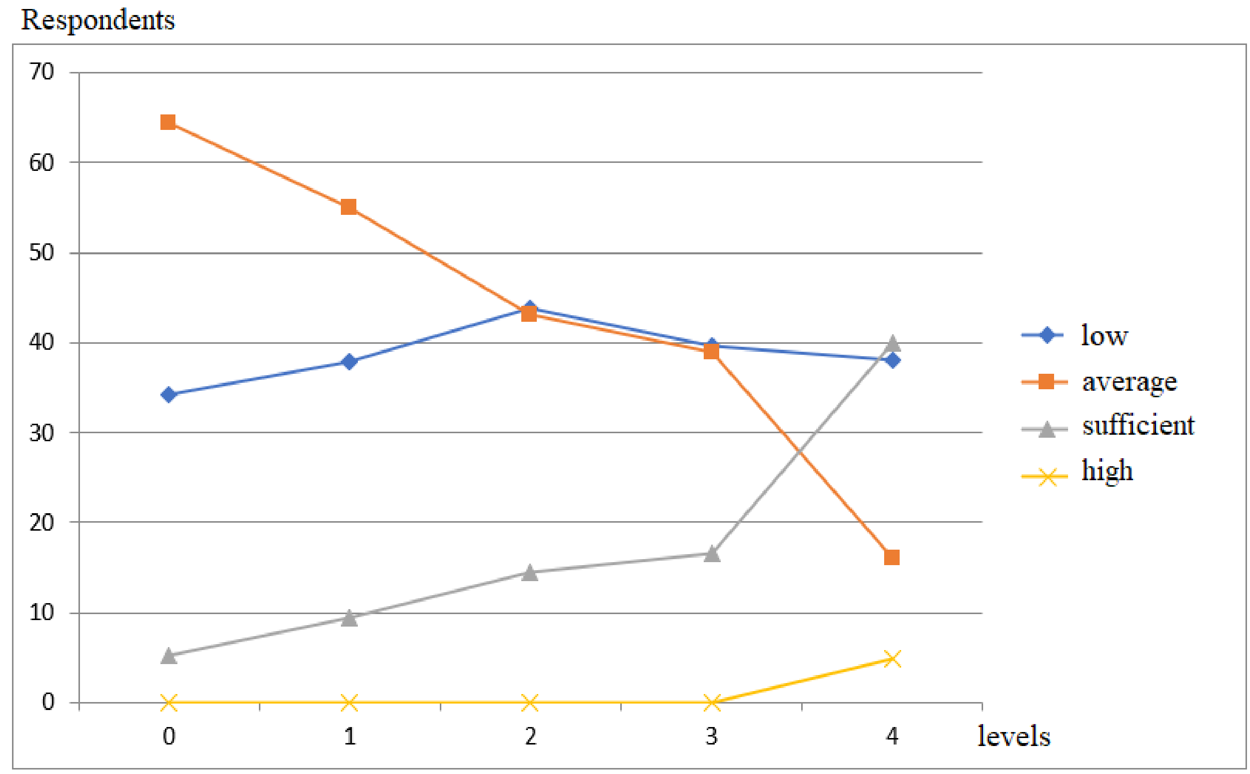

Figure 2.
Quality development trend.

The fact that a high level of competence achieved through the information and educational environment was observed only in isolated cases is seen as a reflection of the specific nature of the initial stage in the formation of the phenomenon studied [29-33]. This specificity lies in the fact that, during the bachelor's interaction with the information and educational environment, the foundations are laid for the purposeful use of one's capabilities and behavioral patterns in solving professional tasks. At the same time, all of these are aimed not only at acquiring knowledge, skills, and abilities but also at developing readiness for professional self-determination and fostering technical thinking [34-37].

Based on the correlation between the conditions for competence formation and readiness for professional self-determination (Table 1), a diagnostic assessment was carried out to evaluate levels of readiness for self-determination and the influence of the information and educational environment on their successful development. In this context, indicators of readiness levels for professional self-determination within the process of IABL were developed (Table 3).

The developed framework reflects indicators that characterize students' readiness levels for professional self-determination within the context of IABL.

Table 3.
Levels of formation of the components of readiness for professional self-determination.

Components of Readiness for PSD	Levels of formation of the components of readiness for professional self-determination			
	low	**average**	**sufficient**	**high**
Motivational	Negative cognitive and professional motivation, lack of aspiration for professional and personal development.	Presence of a positive attitude toward studies and future profession, along with a motivated desire to attain an appropriate social status.	Presence of a stable professional interest and high cognitive activity.	Predominance of positive intrinsic motivation for professional and cognitive activities during the learning process.
Content-related	Low level of knowledge, skills, and abilities in the field of technical disciplines; low self-esteem.	The presence of isolated, unsystematic knowledge and skills that are not always sufficient for solving professional tasks.	Successfully applies knowledge to solve educational and cognitive tasks within the discipline, but still requires teacher assistance.	Well-developed system of knowledge, development of a personal style, and proficiency in skills and abilities.
Technological	General academic skills and abilities are poorly developed.	Low level of independence. The presence of certain difficulties in carrying out professional self-determination.	Ability to evaluate the results of one's own activity.	Successfully applies knowledge to solve complex educational and cognitive tasks. Ability to distinguish between one's ideal self and real self.

An experimental study was conducted with first- and second-year students of Kazakhstani universities. During the pedagogical experiment, control and experimental groups were formed among students majoring in "Electric Power Engineering." At the ascertaining stage of the experiment, the levels of students' readiness for professional self-determination were identified using methods such as observation, surveys, and testing. These levels were evaluated based on criteria and indicators that define this personal quality.

To determine the level of readiness for professional self-determination at the formative stage, the methodology used at the ascertaining stage was applied. The level of formation of the motivational component was assessed through surveys. Analysis showed that students demonstrated a higher interest in future professional activities compared to the initial state, and an increase in motivation was also observed.

The level of the content-related component of readiness was assessed based on exam results, using the number of points scored by the student within the university rating system developed by the educational and methodological commission. The levels were classified as follows:

1 - High level – above 67%.
2 - Sufficient level – 52%.
3 - Average level – 48%.
4 - Low level – 44%.

The level of formation of the technological component of readiness was determined by evaluating the ability to analyze problem situations when solving physics problems, to choose appropriate tools and methods for problem-solving, as well as the student's creative activity (such as participation in conferences, Olympiads, competitions, etc.), and the ability to work in a team.

Table 4.
Status of formation of student readiness levels for professional self-determination (in %).

Levels of Formation, %	Components					
	Motivational		**Content-related**		**Technological**	
	Stages					
	Ascertaining	**Formative**	**Ascertaining**	**Formative**	**Ascertaining**	**Formative**
low	45.2	14.6	47.8	20.1	75.4	45.2
average	37.2	30.2	42.2	62.9	21.6	31.3
sufficient	12.6	46.7	6.5	12	3	18.7
high	5.0	8.5	3.5	5	-	5

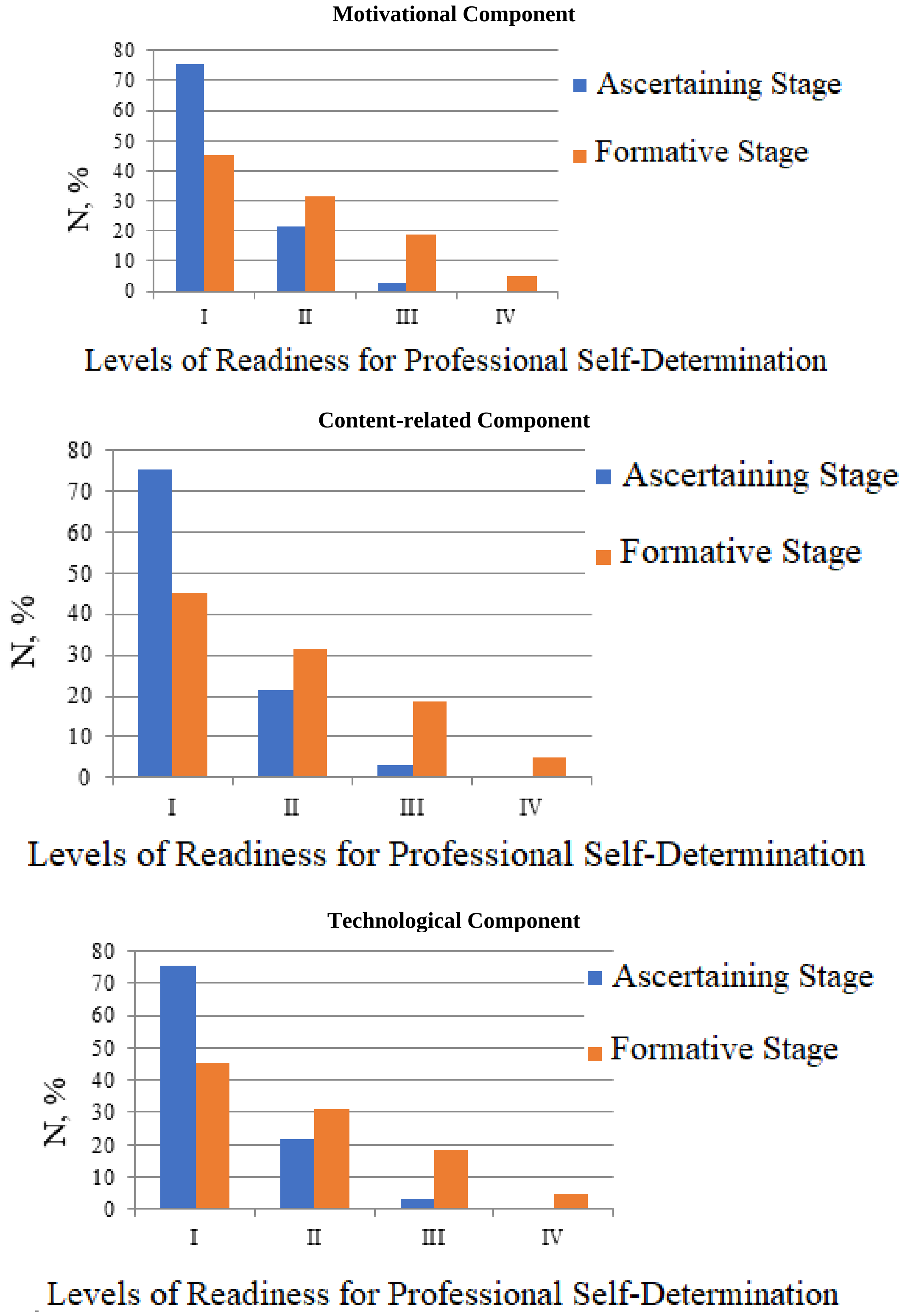

Figure 3.
Distribution of students by levels of formation of components of readiness for professional self-determination, in %.

4. Conclusions

The analysis of the obtained results shows that, compared to the ascertaining stage, the majority of students demonstrated sufficient and high levels of readiness for professional self-determination. The gap was especially significant in the indicators of the technological component. This is due to the fact that the methodology for developing readiness for professional self-determination was focused on activity-based models.

The study of the motivational sphere shows that 47% of students have a stable professional interest and high cognitive activity. The level of students' knowledge has increased due to the use of the information and educational environment aimed at developing the personal qualities of the future specialist.

Based on the methodological principles underlying the model we developed (Figure 1), we assumed that the formation of competence and readiness for professional self-determination are closely interconnected and mutually influential. Therefore, at the final stage, we calculated the correlation coefficients between the formed competencies and levels of readiness for professional self-determination. These were found to be 0.631 and 0.667. The obtained correlation values confirm the presence of a relationship between the development of the personal qualities of a future specialist and academic success.

Thus, the identified structure of interrelations within the information and educational environment is justified both theoretically and supported by experimental evidence.

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