International Journal of Innovative Research and Scientific Studies, 8(9) 2025, pages: 137-151

IJIRSS International Journal of Innovative Research & Scientific Studies

ISSN: 2617-6548

URL: www.ijirss.com

Methodological foundations for developing research competencies of prospective physics teachers through the example of X-ray diffraction

Tleubek Dalabayev[1*], Makpal Nurizinova[2], Mazhyn Skakov[3], Ali Coruh[4]

[1,2,3]Sarsen Amanzholov East Kazakhstan University, 30th Guards Division 34/1, 070000 Oskemen city, Kazakhstan.
[4]Sakarya University, Kemalpaşa, Esentepe Campus, University Cd., 54050 Serdivan/Sakarya city, Turkey.

Corresponding author: Tleubek Dalabayev (*Email: dalabaevtleubek@gmail.com*)

Abstract

Research competence is a key component in the professional preparation of future physics teachers, as it directly contributes to their ability to integrate scientific inquiry into teaching practice. This study aims to design and validate a methodological framework that strengthens research skills within the context of STEM education, using X-ray diffraction as a central phenomenon for instruction. The research employs innovative STEM-oriented pedagogical approaches that emphasize inquiry-based learning, interdisciplinary integration, and the application of information and communication technologies (ICT). A large-scale educational experiment was conducted across two universities, involving 148 undergraduate and graduate students, 50 university faculty members, and 43 secondary schools in two regions. Data were collected through surveys, diagnostic assessments, and structured evaluations to measure the quality of student learning outcomes. Based on the findings, an elective course on X-ray diffraction was developed, accompanied by comprehensive teaching materials and an electronic training manual. The implementation of this elective resulted in a 22.5% increase in students' educational performance, thereby confirming the effectiveness of the proposed methodology. The results suggest that integrating STEM-based elective courses grounded in specialized scientific phenomena not only enhances the research competencies of prospective physics teachers but also contributes to raising the overall quality of physics education in higher education institutions.

Keywords: Future physics teacher, Laboratory work, Research competency, STEM.

DOI: 10.53894/ijirss.v8i9.10635
Funding: This research is supported by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant Number: AP19579398, AP14870844).
History: Received: 26 August 2025 / **Revised:** 23 September 2025 / **Accepted:** 26 September 2025 / **Published:** 13 October 2025

Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Publisher: Innovative Research Publishing

1. Introduction

The level of research competence acquired by university students in general, and by prospective physics teachers in particular, has a direct impact on the quality of education and the effectiveness of their future professional practice. Consequently, considerable attention in educational research is devoted to the development of research competencies through innovative pedagogical strategies, especially within the framework of STEM (science, technology, engineering, and mathematics) education.

Modern universities are equipped with sophisticated experimental and analytical instruments—such as transmission electron microscopy (TEM), scanning electron microscopy (SEM), X-ray fluorescence (XRF), electron paramagnetic resonance (EPR), nuclear magnetic resonance (NMR), and infrared (IR) spectroscopy—most of which rely on physical principles of wave diffraction and interaction. While these tools are widely utilized for scientific research, their potential as educational instruments for cultivating research skills in future teachers has not been sufficiently realized.

In this context, X-ray diffraction represents a particularly promising avenue. As Bunaciu, et al. [1] emphasize, X-ray diffraction is one of the most rapidly advancing techniques in material analysis and offers direct opportunities for developing students' investigative and analytical skills. Nevertheless, an analysis of current curricula shows a lack of structured methodologies for incorporating laboratory-based activities on electron and X-ray diffraction into teacher training programs.

Therefore, integrating the use of diffractometers into educational settings, in combination with STEM-based approaches and digital learning resources, can provide an effective pathway to enhance the research competencies of future physics educators. Building on this rationale, the present study aims to design and test a methodology for fostering research skills through X-ray diffraction–based instruction. Specifically, the objectives of this study, formulated in accordance with the pedagogical principles highlighted by Hattie [2] are as follows:

1. To evaluate the current state of research abilities among prospective physics teachers and develop strategies for their enhancement;
2. To design a framework and create digital instructional resources for a sequence of investigative laboratory activities utilizing an X-ray diffractometer;
3. To conduct a pedagogical experiment in order to assess students' understanding of X-ray diffraction and to measure the extent of improvement in their research competencies.

2. Literature Review

Recent studies highlight the importance of integrating research skill development into higher education curricula. For example, Tai and Omar [3] examined this issue within the framework of Education 4.0, emphasizing the urgency of equipping students with research-oriented capabilities. Other scholars have proposed solutions by incorporating digital and STEM-based technologies [4-17]

These works address research skill formation from different perspectives, such as digital learning, STEM leadership, project-based learning, and ecological approaches. However, despite this progress, the application of advanced scientific instruments for fostering research competencies among physics teacher candidates remains largely unexplored. Notable exceptions include attempts to integrate concepts of wave optics, interference, and diffraction into physics education to promote critical thinking [18, 19]. These studies indicate that wave optics within the general physics curriculum can serve as a methodological foundation for developing scientific reasoning, thereby improving students' understanding of complex phenomena [20].

3.Research Methodology

To tackle the challenges and fulfill the objective, the X-ray diffractometer X'Pert PRO from the National Scientific Laboratory of Shared Use at S. Amanzholov East Kazakhstan University, along with its operator, formed the foundation for the pedagogical experiment. The experiment involved students in their fourth year of study, as well as first- and second-year master's students pursuing degrees in Physics, Physics and Computer Science, and Physics and Mathematics at S. Amanzholov East Kazakhstan University and Khoja Akhmet Yasawi International Kazakh-Turkish University. In total, 148 students, 50 university teachers, and 45 physics teachers from 43 secondary schools in East Kazakhstan and Abai regions participated in the experiment. (Figure 1)

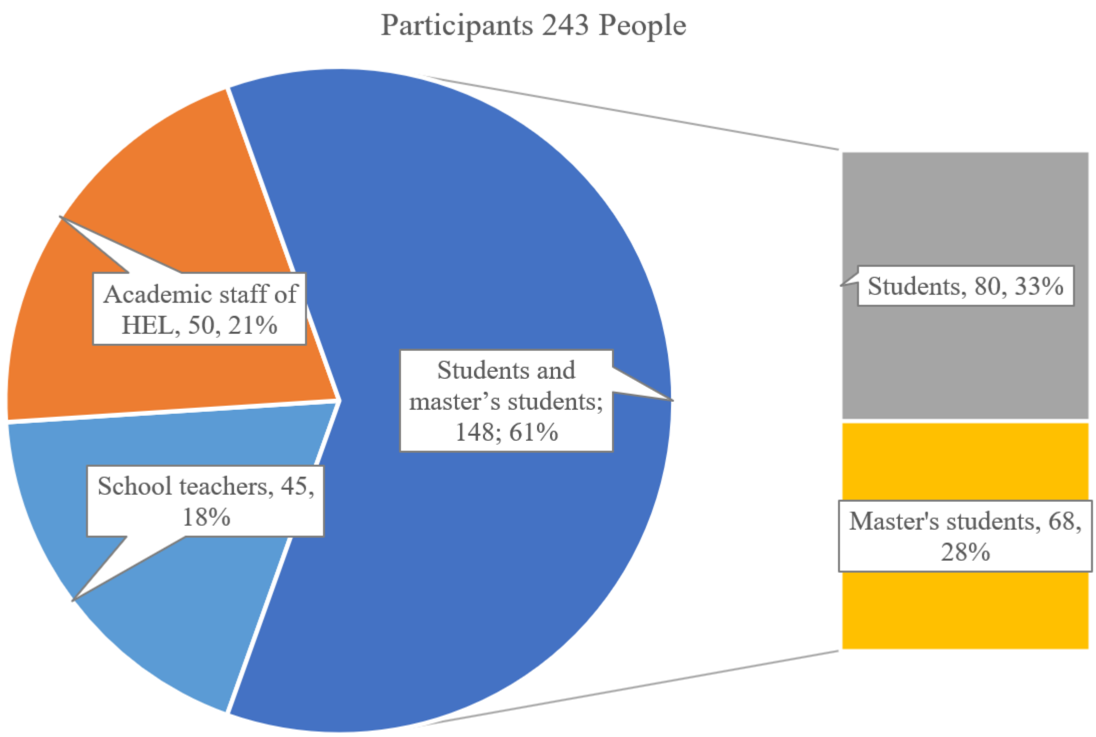


Figure 1.
The individuals involved in the educational experiment.

In this work, we employed a variety of research techniques:

- The methods of comparison, synthesis, and abstraction were used to validate the practicality of the pedagogical experiment approach, in accordance with the guidelines provided by [21].
- Empirical methods, such as observation, surveys, and pedagogical experiments, were employed to investigate and demonstrate the effectiveness of the methodological foundations in developing research skills among future physics teachers, as recommended by Ndihokubwayo, et al. [22].
- A statistical method was employed to collect and analyze experimental data, allowing us to determine the statistical significance of the results obtained in the experimental part of the study, as outlined by Nghiêm-Phú and Nguyễn [23].

The educational trial was implemented in accordance with the principles outlined by Hattie [2]. The trial involved two main groups: the "control" group and the "experimental" group. These groups were further divided into smaller subgroups.

4. Research Results and Discussion

Initially, we evaluated the extent of research proficiency among prospective physics educators through a survery with three response choices (see Table 1,2 and Figure 2).

Table 1.
A survey for bachelor and master's students.

Survey
for Students and Master's Students
Dear student! Please provide complete answers to the questions below.

No	Question	Answer
1	Provide the definition of the phenomenon of diffraction:	
2	What is the difference between geometric optics and wave optics?	
3	Are you familiar with the concept of X-ray diffraction?	1 - Yes 2 - No 3 - I forgot. If you are familiar with it, please provide the definition:
4	Please present the formula based on Bragg-Wulf theory:	1-2dsinθ=nλ 2-5dsinθ=2λ 3- I find it difficult to answer
5	In what year did Conrad Röntgen discover the properties of X-rays?	1-1900 2-1895 3-1850
6	Is it necessary to develop the methodological foundations for forming research competencies of future physics teachers using the phenomenon of diffraction as an example?	1-necessary 2-not necessary 3- I find it difficult to answer If necessary, why?

7	Have you been to the National Scientific Laboratory for Collective Use?	1- yes 2-no 3- I have no information about the laboratory if you are, for what purpose
8	Are you familiar with the X-ray diffractometer equipment at the national scientific research laboratory for collective use based at Sarsen Amanzholov East Kazakhstan University?	1-yes 2-no 3- I find it difficult to answer "If you are familiar, could you please describe the structure and working principle of the X-ray diffractometer?"
9	Are you engaged in scientific research activities?	1-I am currently engaged in it. 2-I have not been involved in scientific research activities. 3-There is no demand for scientific research activities. Why have you not been involved in scientific research activities?
10	Did you encounter any known or unknown difficulties during your involvement in scientific research activities?	1- Yes, difficulties arose 2- No, difficulties did not arise. 3- I find it difficult to answer If difficulties arose, what difficulties did you encounter?

Table 2.
Survey for university professors and academic staff.

For University Teachers
SURVEY
"Dear Colleague! We kindly ask you to provide complete answers to the questions presented below."

Teacher's full name:...
Total number of students: .... of which the number of groups in the Physics major: ....
Please assess how well the skills listed below have been developed in your students using a five-point scale. We kindly ask you to place a '+' sign in the appropriate column.

No.	**Assessable Research Competency**	**1**	**2**	**3**	**4**	**5**
1	Collection and Systematic Analysis of Scientific Data					
2	Ability to Make Preliminary Hypotheses					
3	Setting Personal Goals for the Research Topic					
4	Defining the Objectives of the Research Work					
5	Defining the Subject and Object of the Research					
6	Ability to Present One's Perspective					
7	Applying Observation or Other Research Methods					
8	Implementing or Organizing the Research Work					
9	Analyzing the Results of Scientific Research Work					
10	Documenting and Presenting the Results of Scientific Research Work According to Requirements					

SURVEY
Among physics teachers of secondary schools in the East Kazakhstan region
on the topic
"Development of Methodological Foundations for Forming Research Competencies in Future Physics Teachers Using the Phenomenon of Diffraction as an Example"
aimed at determining its relevance
Dear teacher!
Please answer the question below.

Part 1
1. Full name: 2. Age: 3. Place of work (school): 4. Education: 5. Specialty (or educational program): 6. Academic degree: 7. Academic title: 8. Qualification category: 9. Teaching experience (years):

Part 2
1. In your opinion, what is the level of preparation for future physics teachers?
1.1 ( ) low 1.2 ( ) average 1.3 ( ) high
Because,
2. Factors influencing the quality preparation of future physics teachers:
2.1 ( ) Quality of the faculty 2.2 ( ) Educational resources of the university 2.3 ( ) Quality and modern elective courses
Because,
3. The following teaching technologies should be included in elective courses (or special courses):
3.1 ( ) Advanced innovative technologies 3.2 ( ) STEM technologies 3.3 ( ) traditional teaching technologies
Because,
4. What does the process of forming research competencies in future physics teacher depend on?
4.1 ( ) on the quality of the special course 4.2 ( ) on the pedagogical approach 4.3 ( ) on the application of active learning methods
Because,
5. What role does the Laboratory practicum play in the formation of research competencies in future physics teachers?
5.1 ( ) primary 5.2 ( ) secondary 5.3 ( ) I find it difficult to answer for now
Because,

Part 3
1. In your opinion, is the problem of the low level of research competencies among future physics teacher relevant?
Because:
2. Your opinion on the relevance of the topic "Development of Methodological Foundations for Forming Research Competencies in Future Physics Teachers Using the Example of the Phenomenon of Diffraction"
3. Your suggestion regarding the development of the above-mentioned topic:
4. In your opinion, what other problems exist in the process of preparing future physics teachers?:

Figure 2.
Teacher Surveys for Comprehensive Schools.

The survey was conducted among students and postgraduate students at S. Amanzholov East Kazakhstan University and Khoja Akhmet Yasawi International Kazakh-Turkish University (148 participants), as well as university professors (50 participants), and physics teachers from various secondary schools in East Kazakhstan region and Abai regions (45 participants from 43 schools) (Table 3).

Table 3.
Schools Participating in the Pedagogical Experiment.

No	Name of the school	Number of Physics Teachers Who Participated
1	Branch of JSC NCPC "Örleu" Institute of Professional Development for East Kazakhstan Region	1
2	KSU "School-Center for Additional Education No. 19" for the City of Ust-Kamenogorsk, Department of Education for East Kazakhstan Region	1
3	KSU "Secondary School No. 4" Ust-Kamenogorsk	1
4	KSU "Kamyshevk Complex General Education Secondary School-Kindergarten," East Kazakhstan Region, Samara District	1
5	KSU "Secondary School No. 37" Ust-Kamenogorsk	1
6	KSU "General Education School No. 2" Ust-Kamenogorsk	1
7	KSU "Secondary School No. 23 Named After M. Shayahmetov," for Ust-Kamenogorsk, Department of Education for East Kazakhstan Region	1
8	KSU "Secondary School Named After A. Baitursynov," Glubokovsky District, East Kazakhstan Region	1
9	KSU "Secondary School No. 4 Named After Shakarim," for Shemonaykhin District, Department of Education for East Kazakhstan Region	1
10	KSU "School-Center for Additional Education" Ust-Kamenogorsk	1
11	KSU "Secondary School No. 42" for Ust-Kamenogorsk, Department of Education for	1

	East Kazakhstan Region	
12	KSU "Secondary School Named After Q. Zharylgasinov," Tarbagatai District, Department of Education for East Kazakhstan Region	1
13	KSU "Akzhar School-Boarding College Named After M. Auezov," Tarbagatai District, Department of Education for East Kazakhstan Region	1
14	KSU "Dauletbay Complex School-Kindergarten," Tarbagatai District, Department of Education for East Kazakhstan Region	1
15	KSU "Secondary School No. 5" for Ust-Kamenogorsk, Department of Education for East Kazakhstan Region	1
16	KSU "Secondary School No. 17 Named After M. Auezov," for Ust-Kamenogorsk, Department of Education for East Kazakhstan Region	1
17	KSU "Liceum No. 11" for Ust-Kamenogorsk, Department of Education for East Kazakhstan Region	1
18	KSU "Secondary School No. 22" for Ust-Kamenogorsk, Department of Education for East Kazakhstan Region	1
19	KSU "Profiling School" for Ust-Kamenogorsk, Department of Education for East Kazakhstan Region	1
20	KSU "Glubokovskaya Secondary School Named After Y. Altynsarin," for Glubokovsky District, Department of Education for East Kazakhstan Region	1
21	KSU "Uvarovo Secondary School," for Glubokovsky District, Department of Education for East Kazakhstan Region	1
	Abai Region	
1-22	KSU "Urban Multidisciplinary Kazakh School-Gymnasium" of the Department of Education for Ayagoz District, Abai Region	1
2-23	KSU "Regional Specialized Lyceum 'BILIM-INNOVATION' for Gifted Children of the City of Semey," Department of Education for Abai Region	1
3-24	KSU "Secondary General Education School No. 25" of the Department of Education for the City of Semey, Abai Region	1
4-25	KSU "Коктal Secondary School-Kindergarten" of the Department of Education for Urdjar District, Abai Region	2
5-26	KSU "Secondary General Education School No. 18" of the Department of Education for the City of Semey, Abai Region	1
6-27	KSU "Kazakh Secondary School Named After Alikhan Bokeikhan" of the Department of Education for Borodulikhinsky District, Abai Region	1
7-28	KSU "Borasinskaya Secondary School-Kindergarten" of the Department of Education for Beskaragai District, Abai Region	1
8-29	KSU "EginSui Secondary School-Kindergarten" of the Department of Education for Urdjar District, Abai Region	1
9-30	KSU "Specialized Male Lyceum-Boarding School 'Zhas Ulan' Named After Sh. Ualikhanov for Gifted Children," Abai Region	1
10-31	KSU "Gorny General Secondary School" of the Department of Education for Ayagoz District, Abai Region	1
11-32	KSU "Multidisciplinary Gymnasium No. 5 Named After Shakarim" of the Department of Education for the City of Semey, Abai Region	1
12-33	KSU "Secondary General Education School No. 23" of the Department of Education for the City of Semey, Abai Region	2
13-34	KSU "Secondary School Named After Duysenbi Kalmataev" of the Department of Education for Zharminsky District, Abai Region	1
14-35	KSU "Georgievskaya Secondary School" of the Department of Education for Zharminsky District, Abai Region	1
15-36	KSU "Economic Lyceum" of the Department of Education for the City of Semey, Abai Region	1
16-37	KSU "Kazakh School-Gymnasium Named After K. Boztaev" of the Department of Education for Ayagoz District, Abai Region	1
17-38	KSU "Secondary General Education School No. 4" of the Department of Education for the City of Semey, Abai Region	1
18-39	KSU "Secondary School Named After K. Shakenov" of the Department of Education for Zharminsky District, Abai Region	1
19-40	KSU "Suykbulak Secondary School" of the Department of Education for Zharminsky District, Abai Region	1
20-	KSU "Secondary School Named After Baurzhan Momyshuly" of the Department of	1

41	Education for Urdjar District, Abai Region	
21-42	KSU "Secondary School No. 17 Named After P. Teryaev" of the Department of Education for Zharminsky District, Abai Region	1
22-43	KSU "Secondary School Named After Sasan Bi" of the Department of Education for Aksuat District, Abai Region	1
Total	43	45

The survey consisted of three main thematic questions, and the responses of each group of participants were expressed as percentages (see Figure 3).

Survey No. 1. Among the students and postgraduate students of the programs under investigation at the universities, the following results were obtained:

95% reported that there are issues with research work.

100% reported that they are unaware of how an X-ray diffractometer operates.

100% responded that the issue of "developing methodological foundations for forming research competencies among future physics teachers using the example of X-ray diffraction" is relevant.

Survey No. 2. Among university teachers, the following results were obtained:

90% answered that there are problems with research work among physics students;

100% replied that the aforementioned problem can be solved by introducing a special course;

100% answered that the problem of "developing methodological foundations for the formation of research competencies among future physics teachers using the example of X-ray diffraction" is relevant.

Survey No. 3. Among secondary school teachers, the following results were obtained:

85% answered that there are problems with research work among future physics teachers;

100% replied that the aforementioned problem can be solved by introducing a special course;

95% answered that advanced pedagogical technologies, including STEM education technology, should be used in the methodology of teaching the special course;

100% replied that the problem of "developing methodological foundations for the formation of research competencies among future physics teachers using the example of X-ray diffraction" is relevant.

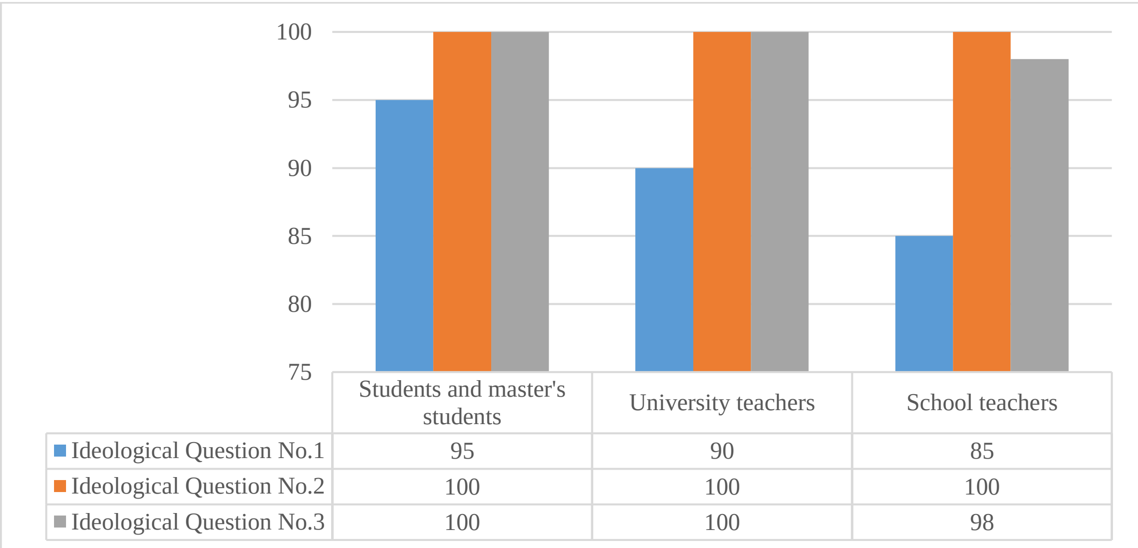


Figure 3.
The outcomes of the ideological inquiries in the poll, measured on a scale of 100-point scale.

The fundamental ideological inquiries yielded the following average outcomes:

Ideological Question No.1: Is there a problem with research work among future physics teachers? On average, the results of three surveys suggest that 90% of future physics teachers encounter difficulties with research work.

Ideological Question No. 2: How can the issue of developing research skills in future physics teachers be resolved? On average, the results of three surveys indicate that 100% of respondents believe that this issue can be addressed by introducing a specialized course.

Ideological Question No. 3: Is the issue of "developing methodological foundations for fostering research skills in future physics teachers through the example of X-ray diffraction" pertinent? On average, the results of three surveys indicate that 100% of respondents consider this issue relevant and recommend solutions for it.

In the open-ended survey, 95% of respondents agreed that advanced pedagogical methods, including STEM education technology, should be incorporated into the training program for future physics teachers.

The survey was conducted among 243 participants, including 148 students and master's students, 50 university professors, and 45 physics teachers from general education schools. The majority of respondents acknowledged that future physics teachers lack research skills and face difficulties in conducting research.

The respondents suggested that this issue could be resolved by introducing a specialized course into the curriculum and developing a methodological framework for fostering research competencies in future physics teachers, using X-ray diffraction as an example. They also emphasized the importance of incorporating advanced pedagogical methods, including STEM education technology, into the training program for physics teachers.

Consequently, to tackle these objectives, we established a framework for cultivating research skills in aspiring physics educators through STEM-based education. This framework encompasses instructional and methodological guides, as well as digital learning resources.

In Figure 5 a schematic representation of the methodology for fostering research abilities in future physics teachers is depicted. It is clear that the specialized course "X-ray Diffraction" encompasses not only theoretical sessions but also practical exercises and independent projects (see Figure 4).

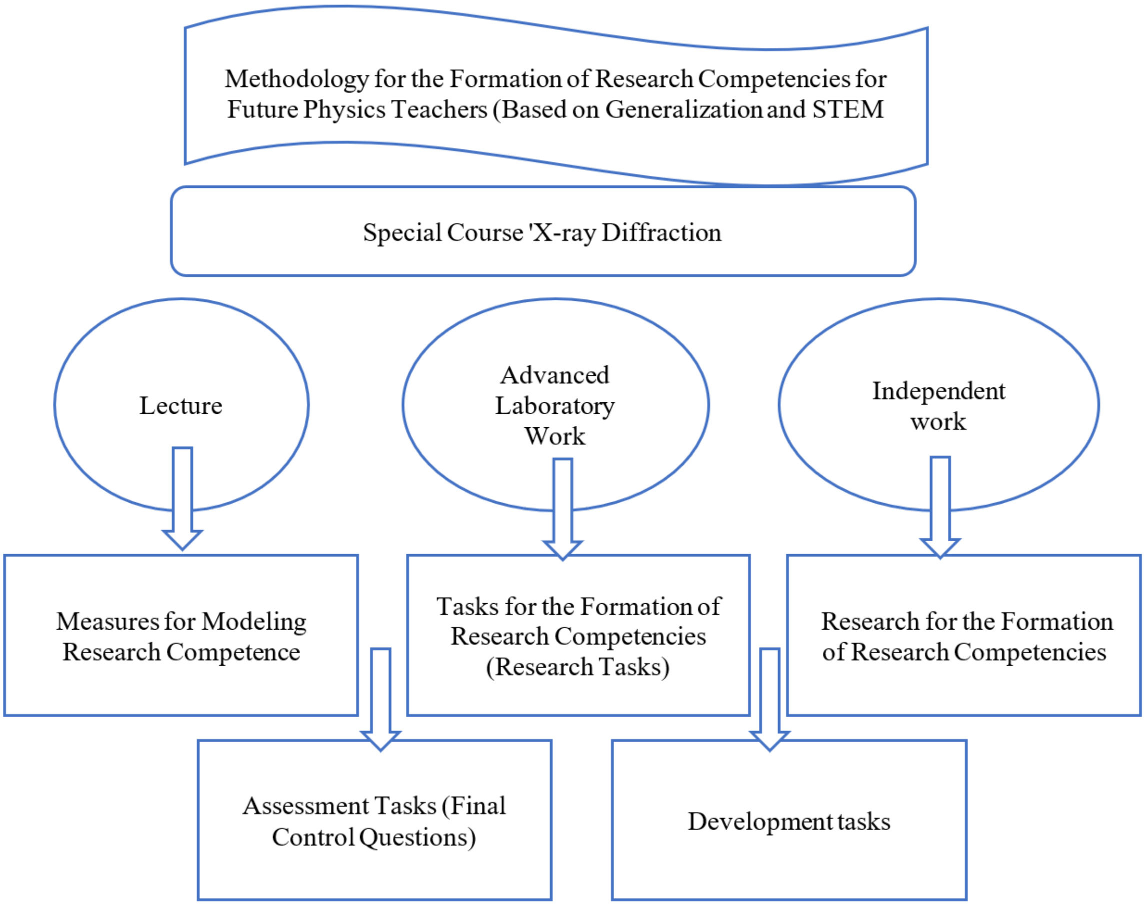


Figure 4.
A schematic representation of the approach to developing research skills for future physics teachers (abbreviated).

Figure 5 depicts the framework of the methodological approach, with the central element being the specialized course, the efficacy of which was validated through a subsequent educational experiment (see Figure 5).

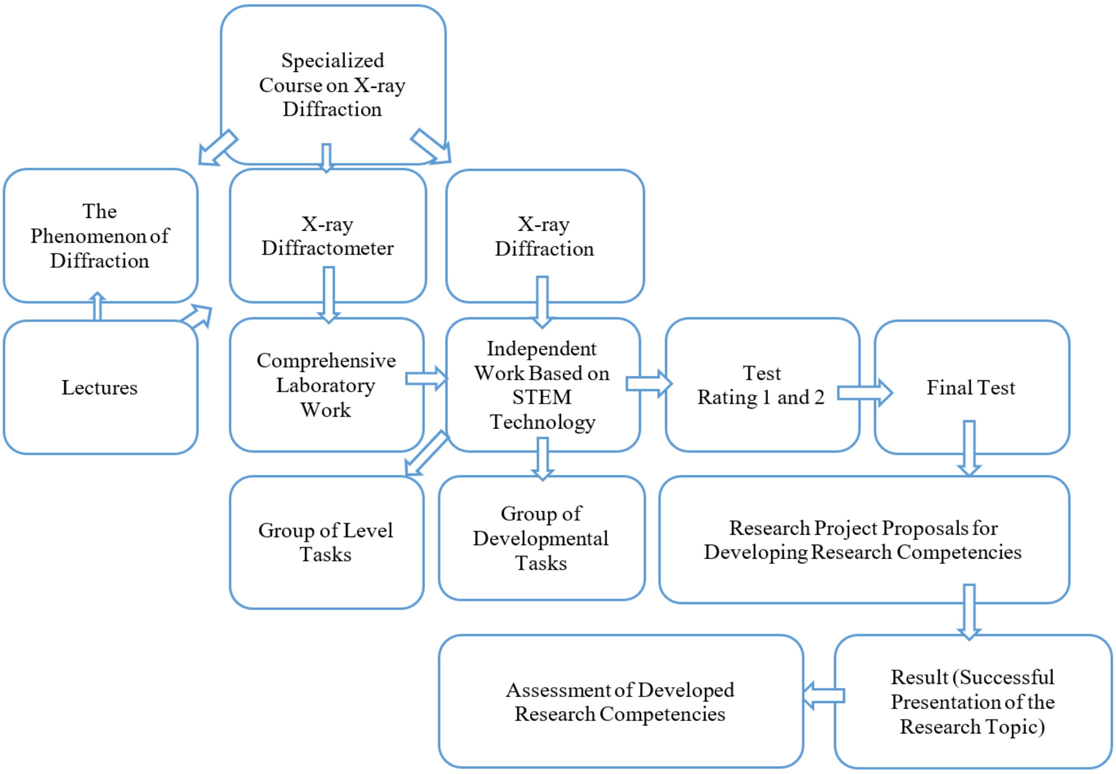


Figure 5.
The conceptual framework of the specialized course.

Consequently, in line with the framework for cultivating research abilities in future physics teachers, an elective course titled "X-ray Diffraction" was created and integrated into the curriculum for fourth-year students enrolled in the educational programs "Physics," "Physics and Computer Science," and "Physics and Mathematics," as well as for first- and second-year master's students in the same programs at both universities.

Furthermore, an educational guide titled "Theoretical Foundations of X-ray Diffraction" was developed and tested, and it has been endorsed by the Academic Council of East Kazakhstan State University named after Sarsen Amanzholov for use in the educational process. The educational guide has been granted a certificate "on the inclusion of information in the state register of rights to objects protected by copyright".

The educational guide provides a comprehensive overview of the theoretical principles of X-ray diffraction, with theoretical information and accompanying questions. To reinforce the theoretical knowledge, students engage in a series of laboratory exercises focused on X-ray structural analysis. To support this learning process, an educational and methodological manual titled "A Collection of Exercises in X-ray Structural Analysis" has been developed. This manual includes specialized tasks based on STEM technology for independent work, designed to foster students' research skills. These tasks are intended to enhance students' ability to critically evaluate the results obtained.

The educational manual comprises ten chapters, which are logically interconnected, contributing to a deeper understanding and mastery of the course material [24].

The laboratory activities, which incorporate elements of research and STEM education, are designed to enhance the research skills of future physics teachers. The tasks and the overall approach to conducting the series of experiments have been developed with the application of STEM education technology. Furthermore, the teacher is provided with evaluation criteria for the laboratory activities.

The series consists of three laboratory activities:

Laboratory Work No.1: Familiarization with the operation of the X-ray diffractometer.

Laboratory Work No.2: Performing X-ray diffraction analysis on aluminum.

Laboratory Work No.3: Conducting diffraction analysis on copper to identify the second unknown component.

For instance, [25]. Let us delve into Laboratory Work No. 3, which focuses on the topic of "Determining the Second Unknown in an Alloy through Diffraction Analysis of Copper." The goal of this work is to create a diffractogram of copper and identify the unknown element in the alloy. To achieve this, students must:

1. Study the theoretical aspects of the laboratory work.
2. Review the procedure for conducting the experiment.
3. Examine the alloy visually.
4. Work with the operator to start the diffractometer.
5. Obtain the diffractogram of the sample. Decode and analyze the data obtained (creating the diffractogram, data analysis).
6. Perform the necessary calculations using the Bragg-Wulff formula.
7. Compare the results with the data from the diffractogram database.

8. Identify the unknown phase.

After finishing the main part of the laboratory work, students proceed to work independently. They are provided with:

1. Test tasks.
2. Special developmental tasks based on STEM.
3. Problem-solving tasks.

We believe that by completing a series of laboratory works and assignments, future physics teachers will be prepared for independent research and will acquire their initial skills in scientific research. In our view, the independent execution of laboratory research is a crucial aspect of the methodology for developing research competencies in future physics teachers through STEM education. Laboratory sessions offer opportunities to develop skills in conducting experiments and executing scientific projects.

Therefore, the culmination of the process of developing research abilities for future physics teachers, marked by the clear implementation of STEM educational approaches, involves students completing a series of specially designed research laboratory activities focused on X-ray diffraction. These activities showcase the practical relevance of the educational research conducted at an empirical level. A schematic representation of the progression of a student from completing standard physics assignments to independently conducting educational laboratory activities can be depicted as a sequence. To foster research skills in future physics teachers, we propose a methodological framework that encompasses educational and instructional materials, both in print and digital formats, which have been developed in accordance with STEM educational technology.

Subsequently, to gauge the advancement in understanding of X-ray diffraction and evaluate the growth in research abilities, we conducted a pedagogical experiment. The experiment was designed using the methodology developed by Professor John Hattie. Throughout the experiment, we maintained strict adherence to academic integrity and transparency.

Table 4 summarizes the findings of the experimental work, which demonstrate the efficacy of integrating STEM education into the process of conducting research laboratory experiments on X-ray diffraction (Table 4).

Table 4.
Results of Student Testing.

No.	Information	Control group	Experimental group
1	Students amount	72	76
2	Average age	21	22
3	Teaching Technology and Its Features	1-Traditional Teaching Technology (Application in the Laboratory Work Process) 2-Traditional Textbooks and Material-Technical Resources 3-Traditional Assignments and Tests	1-STEM Technology Elements Based on the Special Course "X-ray Diffraction" (Practical Application of Specially Designed Laboratory Works Incorporating STEM Elements) 2-Educational and Instructional Materials, Their Electronic Versions, Scientific Laboratory Equipped with Modern X-ray Diffractometer 3-Special Assignments Aimed at Developing Research Competencies
4	Entry Test (Assessment of Knowledge Quality on X-ray Diffraction)	65.4 %	71.3 %
5	Exit Test (Assessment of Knowledge Quality on X-ray Diffraction)	72.6 %	93.8 %
6	Change in Knowledge Quality	growth 7.2 %	growth 22.5 %
7	Final Survey of Students and Master's Students Aimed at Determining the Growth of Research Competencies Development	It is evident that 145 respondents indicated that they now understand what research work is and can independently engage in scientific research. Only 2 respondents stated that there is no problem, although they do encounter certain difficulties that they find hard to specify.	

As is well-known, a thorough understanding of educational materials in a particular subject requires not only a grasp of the theoretical information presented in the instructional materials and relevant literature, but also the ability to answer control questions. The theoretical knowledge acquired was put into practice by students during the laboratory work, which was conducted in accordance with the provided instructional materials and the associated tasks. Following this, an exit test was administered to evaluate the quality of the knowledge acquired by the end of the experiment. The purpose of this assessment was to compare the quality of knowledge gained by students who learned through traditional methods with those who learned through STEM technology. Figure 7 illustrates the results of the students' testing in the form of histograms (see Figure 6).

In the context of the pedagogical experiment, specifically the sample, the confidence interval will be 95%. Therefore, we employ the following error formula:

E=1/^n

The error rate is 6.4%, based on a sample size of 243 individuals. This is a reasonable level of error, considering that the exact number of participants is known in the educational experiment. All participants provided thorough responses to all questions and fully met all criteria, actively engaging in the process.

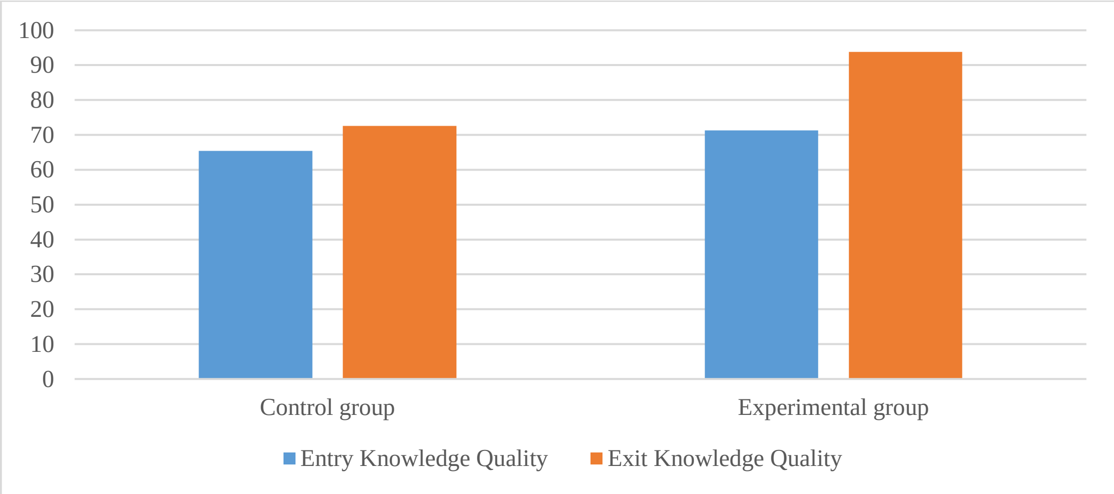


Figure 6.
The outcomes of testing in a hundred-point framework.

Each of the ten key components of the methodology for the laboratory exercise «Determining the Second Unknown in an Alloy Through Diffraction Analysis of Copper» designed to evaluate the efficacy of STEM education components in the physics laboratory process has proven its effectiveness, as per [26]. Specifically:

Element 1: The use of thought-provoking questions and assignments that foster critical thinking, which were based on the application of STEM education principles during the laboratory work on X-ray diffraction physics, received a positive response from 90% of participants. The presented keywords successfully achieved their objective by fully illuminating the topic during the execution of the laboratory work. Therefore, Component 1 fully accomplished its intended purpose and yielded positive outcomes.

Element 2: Our plan for the educational experiment was to split the students into two groups. To ensure that the control and experimental groups received different instructional approaches, we assigned students to groups using the "Leader" method. The control group was divided into six subgroups, while the experimental group was also divided into six subgroups, as shown in Table 5.

Table 5.
Results.

Participants of pedagogical experiment	**Control group**						**Experimental group**					
Number of participants	72						76					
Subgroups	1	2	3	4	5	6	1	2	3	4	5	6
Students, master's students	12	10	11	12	12	15	13	10	13	13	12	12

Element 3: The students were presented with a series of questions related to the topic, and they were encouraged to provide thoughtful responses. The teacher and students engaged in a discussion, allowing for a deeper understanding of the subject matter.

Element 4: We examined methods that incorporated elements of STEM education elements to determine if similar phenomena observed in laboratory work could be observed in other subjects, such as other natural sciences). Examples of cross-disciplinary communication were provided. The Wulf-Bragg formula was explained both mathematically and physically.

Element 5: The laboratory work was conducted in a structured manner, following the work plan. The primary tasks were completed with the assistance of an operator. Based on the results obtained, the students drew conclusions.

Element 6: During the laboratory work on X-ray wave diffraction, the obtained results were thoroughly analyzed, and the physical principle of the diffractometer's operation and its areas of application were discussed, which constituted a key component of STEM education.

Element 7: The students in the group independently formulated their conclusions, which were then reviewed by the entire group. During the physics laboratory, they assessed their work based on the provided criteria.

Element 8: During the laboratory work on the specialized course «X-ray Diffraction», the students completed «confirmatory tasks» designed to validate the laboratory work in the context of STEM education were fully completed. The proposed tasks included «Word Cloud», «Formula Composition», «Physical Dictation», «Physical Riddle», and other activities.

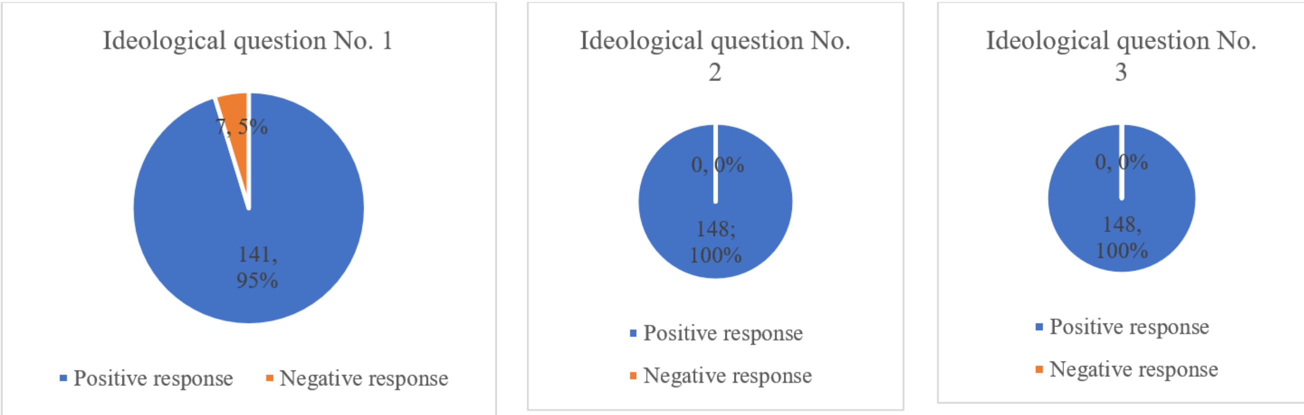
Element 9: The reflection exercise was conducted after the laboratory practicum (session). The reflection confirmed our hypothesis about the efficacy of using STEM education in the laboratory work on X-ray diffraction.

Element 10: For future physics teachers, we have prepared a list of tasks and topics for independent exploration. The work on these topics has already started.

Consequently, the significance was validated by the findings of the survey, which included fundamental inquiries. The ideological questions proved to be highly effective.

The following are the numerical results of the survey:

The students and graduate students responded to the ideological questions as follows (see Figure 7). Regarding the first ideological question, 141 respondents stated that there are issues with research work among physics students, while 7 respondents were undecided (see Fig. 7A). Regarding the second ideological question, 148 respondents indicated that they were unaware of the principle of operation of an X-ray diffractometer (see Fig. 7B). Regarding the third ideological question, 148 respondents agreed that the problem of "developing methodological foundations for the formation of research competencies in future physics teachers using X-ray diffraction as an example" is relevant (see Fig. 7C).



A) Ideological question No.1 B) Ideological question No.2 C) Ideological question No.3

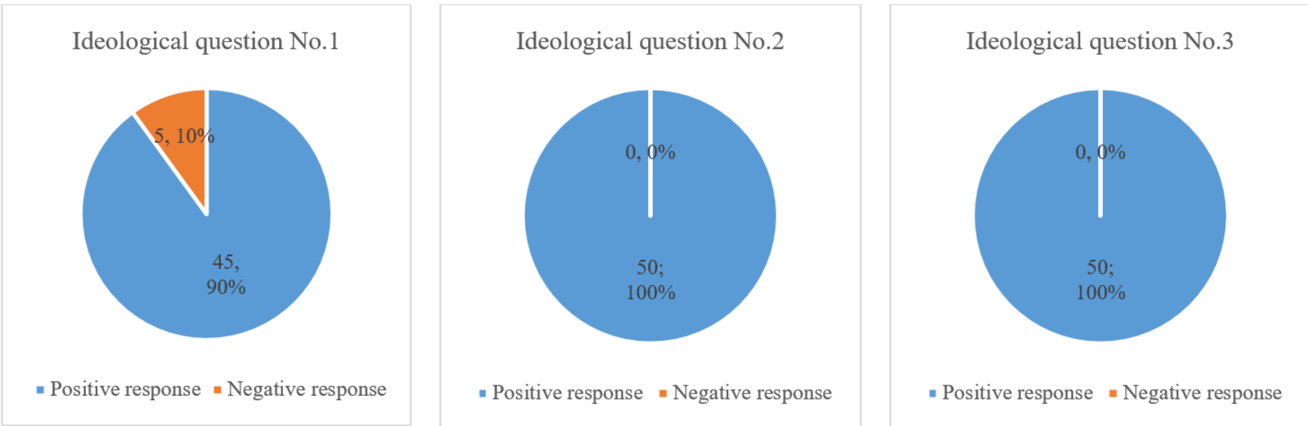
Figure 7.
Survey №1 results of students and master's students.

The teachers at the university who participated in the educational experiment responded to the fundamental questions regarding the subject matter as follows (see Figure 8).

45 of the respondents acknowledged that there are difficulties with research work among physics students, while 5 were unsure (see Figure 8).

50 of the respondents suggested that this issue could be addressed by introducing a specialized course (see Fig. 8B).

50 of the respondents agree that the problem of "developing the methodological foundations for fostering research skills in future physics teachers through the use of X-ray diffraction as an example" is relavent (see Fig. 8C).



A) Ideological question No. 1 B) Ideological question No. 2 C) Ideological question No.3

Figure 8.
Survey №2 results of university teachers.

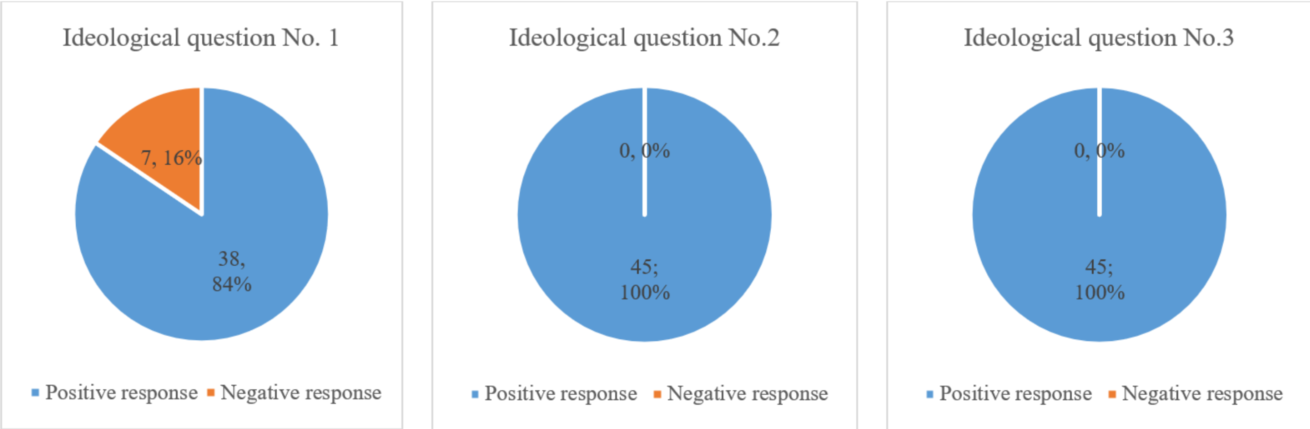
Physics teachers from comprehensive schools actively engaged in the educational experiment. They provided comprehensive responses to all inquiries (see Figure 9):

20 participants suggested that advanced contemporary educational methods, including STEM education, should be actively incorporated into the methodology of teaching physics at universities.

Regarding the ideological questions, 38 participants indicated that there are concerns regarding research work among future physics teachers, while 7 participants were undecided (see Figure 9).

45 participants stated that this issue could be addressed by introducing a specialized course (see Figure 9).

45 participants agreed that the problem of "developing methodological foundations for fostering research skills in future physics teachers using X-ray diffraction as an example" is pertinent (see Figure 9).



A) Ideological question No. 1 B) Ideological question No. 2 C) Ideological question No. 3

Figure 9.
Survey №3 results of physics teachers from general education schools.

Consequently, the findings of the surveys conducted among the participants in the experiment indicate that there is a substantial problem with the development of research skills among future physics teachers in universities. By "research skills" in this context, we mean, in line with Howard, et al. [4] a combination of specific personal attributes and research abilities that allow an individual to excel in any type of research endeavor, encompassing the acquisition, analysis, and assessment of scientific data.

In our pedagogical experiment, we adhere to the view of Tai and Omar [3] who believes that when designing the research activities of students, the model and methodology of research developed and accepted in the field of science over the past few centuries serve as the foundation. This model is accomplished by increasing the desire to engage in a general cultural sense, while in education, the aim of research activities is to equip students with the functional skill of research as a universal means of comprehending reality. This is achieved by enhancing motivation for educational activities and activating the learner's personal involvement in the educational process. The foundation for this is the acquisition of subjectively new knowledge — knowledge obtained independently that is independently obtained and personally significant for the individual student — as described by Fernández-Batanero, et al. [5].

In our view, the research method is the primary approach to learning through creative activity, which, in our opinion, most effectively fosters the development of research skills. However, according to Skakov and Dalabayev [25] emphasize that, in accordance with the principle of incremental mastery, any novel and complex content of creative activity can only be mastered gradually, one element at a time and one operation at a time.

Berikkhanova, et al. [6] suggest a shift from the research method to the heuristic approach, which, we believe is the most effective for developing research skills in first-year physics students and has been adopted as our foundation. This approach involves the following steps:

1. Breaking down a complex problem into smaller sub-problems.
2. Replacing the original problem with a simpler one that is similar in nature.
3. Returning to the original problem after completing the simpler task.

In previous research, a comprehensive understanding of the complexity and patterns of students learning experiences in physics students has been achieved through the integration of a contextual model of competency development, categories of random competencies, and student records, which form narrative trajectories through learning [7]. In our study, we explore the implications of these findings for education in the field of diffraction.

5. Conclusion

Consequently, this paper outlines a strategy for the cultivation and enhancement of research abilities in future physics teachers through the examination of the physics curriculum's X-ray diffraction section. The guidelines for selecting and constructing a task system, including specially designed problems and laboratory exercises, are presented. These tasks are designed to achieve the research objectives. The findings of the study validate the efficacy of this task system and the approach to its implementation.

Based on a review of psychological, educational, and methodological literature on the subject, the theoretical foundations for preparing future educators for research endeavors are uncovered. It is demonstrated that research abilities are a crucial aspect of the professional development of future physics teachers. The significance of STEM education in fostering research abilities is highlighted, and the principles for selecting criteria to assess the levels of research proficiency in future physics teachers are scientifically substantiated.

The proposed framework has proven to be a versatile model that can serve as a template for other fields in the realm of natural and mathematical sciences.

We have shown that the research abilities of physics students, a specific characteristic that encompasses a harmonious blend of a strong desire to engage in physical research and the capacity to conduct scientific investigations using physical methods, can be cultivated by incorporating elements of STEM education into the laboratory exercises on X-ray diffraction. It has been discovered that the implementation of these STEM components in physics laboratory activities, particularly in the context of diffraction exercises, enhances the level of research abilities among physics students, preparing them for independent research endeavors during their senior years at the university. This, in turn, elevates the level of research abilities among future physics educators.

In the course of this work, the structural framework of research abilities in prospective physics teachers has been established. The criteria for their development have been defined: a positive inclination towards research activities, a sustained interest in exploring scientific sources, a proactive approach to identifying and resolving research challenges, a deliberate and rational execution of the research process, a thorough analysis of research outcomes, a well-founded assessment of the relevance and significance of the findings, a clear and logical presentation and defense of the results, and a strong desire to integrate research into their future careers. The established structural framework and criteria for research abilities have facilitated the development of diagnostic tools for the process of their development in prospective physics teachers.

The findings suggest that the integration of STEM technology components with reproductive techniques in the context of a laboratory practicum on X-ray diffraction enhances the development of research skills in future physics educators.

The research revealed that the research abilities of future physics educators are insufficient and require immediate attention. To address this issue, it is crucial to establish methodological foundations in universities.

To tackle the challenge of enhancing research abilities, a framework for cultivating research expertise in future physics teachers was devised. A pedagogical trial was conducted, showcasing the efficacy of this approach, leading to a 22.5% improvement in knowledge quality. Based on the findings, a model for fostering research skills in future physics teachers through STEM education has been established.

The developed framework has been incorporated into the curriculum of the bachelor's degree programs in Physics, Physics-Computer Science, and Physics-Mathematics at the East Kazakhstan University named after S. Amanzholov and the International Kazakh-Turkish University named after Khoja Akhmet Yasawi.

References

[1] A. A. Bunaciu, E. g. Udriştioiu, and H. Y. Aboul-Enein, "X-ray diffraction: Instrumentation and applications," *Critical Reviews in Analytical Chemistry*, vol. 45, no. 4, pp. 289-299, 2015. https://doi.org/10.1080/10408347.2014.949616

[2] J. Hattie, *Which strategies best enhance teaching and learning in higher education? In D. Mashek & E. Y. Hammer (Eds.), Empirical research in teaching and learning: Contributions from social psychology*. Wiley Blackwell, 2011. https://doi.org/10.1002/9781444395341.ch8

[3] M. K. Tai and A. K. Omar, "Leading teaching and learning in the era of Education 4.0: The development of teacher competency model via structural equation modelling," *International Journal of Management in Education*, vol. 17, no. 2, pp. 130-156, 2023.

[4] S. K. Howard, J. Tondeur, J. Ma, and J. Yang, "What to teach? Strategies for developing digital competency in preservice teacher training," *Computers & Education*, vol. 165, p. 104149, 2021. https://doi.org/10.1016/j.compedu.2021.104149

[5] J. M. Fernández-Batanero, M. Montenegro-Rueda, J. Fernández-Cerero, and I. García-Martínez, "Digital competences for teacher professional development. Systematic review," *European Journal of Teacher Education*, vol. 45, no. 4, pp. 513-531, 2022. https://doi.org/10.1080/02619768.2020.1827389

[6] A. Berikkhanova *et al.*, "Conceptualising the integration of action research into the practice of teacher education universities in Kazakhstan," *Education Sciences*, vol. 13, no. 10, p. 1034, 2023. https://doi.org/10.3390/educsci13101034

[7] S. Dubovicki and R. Jukić, "The importance of acquiring pedagogical and didactic competencies of future teachers – the Croatian context," *Early Child Development and Care*, vol. 187, no. 10, pp. 1557-1568, 2017. https://doi.org/10.1080/03004430.2017.1307839

[8] J. R. Savery, "Overview of problem-based learning: Definitions and distinctions," *Essential Readings in Problem-Based Learning: Exploring and Extending the Legacy of Howard S. Barrows*, vol. 9, no. 2, pp. 5-15, 2015. https://doi.org/10.7771/1541-5015.1002

[9] H. S. Yilmaz, "A study of determination of benchmarks during the new formation of integrated stem leader preparation program," *European Journal of STEM Education*, vol. 7, no. 1, p. 10, 2022. https://doi.org/10.20897/ejsteme/12634

[10] R. Widiyanto, K. Herlina, and D. Andra, "The need analysis of using physic e-module based PjBL- integrated STEM: The preliminary study research as a solution to improve problem-solving skills on light refraction material," presented at the In IOP Conference Series: Earth and Environmental Science IOP Publishing Ltd (Vol. 1796), 2021.

[11] L. Kusuma, Sukarmin, and A. Supriyanto, "The perceptions of teacher and student in senior high school to the needs of STEM-based e-learning in physics learning process," in *Proceedings of the 4th International Conference on Learning Innovation and Quality Education*, 2020, pp. 1-7.

[12] A. Bukusheva, O. Pavlova, A. Hudyakova, and N. Chirkova, "Developing future teachers' research competence in the context of the environmental approach implementation," *Profession-Oriented School*, vol. 11, no. 1, pp. 26–33, 2023. https://doi.org/10.12737/1998-0744-2023-11-1-26-33

[13] D. Imbert Romero, C. Rebollo, C. Cabrera Borges, E. Elósegui, J. Torres, and L. Otero, "Formative research in teacher training: A case study carried out in Uruguay," *International Journal of Educational Research*, vol. 125, p. 102345, 2024. https://doi.org/10.1016/j.ijer.2024.102345

[14] A. Nurramadhani, "Analysis of students stem literacy based on gender differences in science learning," *Journal of Humanities and Social Studies*, vol. 4, no. 1, pp. 21-25, 2020.

[15] S. Khrapatyi, K. Tokarieva, O. Hlushchenko, O. Paramonova, and I. Lvova, "Research on performance evaluation of higher vocational education informatization based on data envelopment analysis," *STEM Education*, vol. 4, no. 1, pp. 51-70, 2024. https://doi.org/10.3934/steme.2023014

[16] M. Selisne, Y. Sari, and R. Ramli, "Role of learning module in STEM approach to achieve competence of physics learning," *Journal of Physics: Conference Series*, vol. 1185, no. 1, p. 012100, 2019. https://doi.org/10.1088/1742-6596/1185/1/012100

[17] M. Maulana, "The application of the STEM-based project-based learning model in physics learning prepares students for independent learning," *Jurnal Teknodik*, pp. 39-50, 2020.

[18] S. Saprudin, S. Liliasari, A. Prihatmanto, and A. Setiawan, "Pre-service physics teachers' thinking styles and its relationship with critical thinking skills on learning interference and diffraction," in *Journal of Physics: Conference Series*, 2019, vol. 1157, no. 3: IOP Publishing, p. 032029, doi: https://doi.org/10.1088/1742-6596/1157/3/032029.

[19] V. Mešić, E. Škaljo, B. Mitrevski, L. Nešić, S. Hatibović, and M. Maličević, "Seeking missing pieces in learning about single slit diffraction: Results from a teacher survey," *Physics Education*, vol. 56, no. 3, p. 035024, 2021. https://doi.org/10.1088/1361-6552/abe992

[20] J. Aragón, E. Benjumea, D. Avila, and S. Horta, "Design and manufacture of a mechanical system for teaching the diffraction phenomenon," *Journal of Physics: Conference Series*, vol. 1219, no. 1, p. 012007, 2019. https://doi.org/10.1088/1742-6596/1219/1/012007

[21] E. Prokopets, "Methodological aspects of the technology of developing electronic textbooks," *Bulletin of the Innovative University of Eurasia* vol. 81, no. 1, pp. 30–37, 2021. https://doi.org/10.37788/2021-1/30-37

[22] K. Ndihokubwayo, J. Uwamahoro, and I. Ndayambaje, "Usability of electronic instructional tools in the physics classroom," *EURASIA Journal of Mathematics, Science and Technology Education*, vol. 16, no. 11, 2020. https://doi.org/10.29333/ejmste/8549

[23] B. Nghiêm-Phú and T. H. Nguyễn, "University lecturers' use of active teaching methods: a segmentation study concerning trust, empowerment, thinking styles and emotional intelligence," *Journal of Asian Business and Economic Studies*, vol. 29, no. 3, pp. 189-204, 2022. https://doi.org/10.1108/JABES-05-2020-0057

[24] M. K. Skakov and T. N. Dalabayev, *X-ray diffraction analysis – a set of research works: Educational and methodological tool*. Oskemen: S. Amanzholov East Kazakhstan University Press, 2024.

[25] M. K. Skakov and T. N. Dalabayev, *Theoretical foundations of x-ray diffraction: Educational tool*. Oskemen: S. Amanzholov East Kazakhstan University Press, 2024.

[26] M. Skakov, A. Choruh, and M. Nurizinova, "The methodological foundations for developing the scientific research competencies of future physics teachers," *Scientific journal Bulletin of the National Academy of Sciences of the Republic of Kazakhstan*, vol. 407, no. 1, pp. 283-294, 2024. https://doi.org/10.32014/2024.2518-1467.673