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Ensuring continuity in science education (on example of physics curriculum)

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ABSTRACT

The relevance of the research stems from the need to study the issues of continuity of the school and university curricula content in science disciplines on the example of the "physics" course. This study aims at identifying the principles of continuity of the content of school curricula and higher education programs in natural sciences in the example of the "physics" course, as well as disclosing methods to ensure the continuity of secondary and higher education in the Republic of Kazakhstan. The primary method in this study is system analysis, which is applied to examine the continuity of the school and university science curricula content, using the "physics" course as an example. Moreover, a theoretical analysis of recent scientific publications was carried out in the research process. The study deals with the problem of maintaining continuity in the general secondary education curricula in the field of natural sciences based on a renewed education program. The study presents the results of the analysis in the form of methodological suggestions and reveals possible barriers to the implementation of lifelong learning.

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1. INTRODUCTION

Continuity is the connection between different stages and phases of development, the essence of which consists of the preservation of certain elements of the whole or of certain aspects of its organization while changing the whole as a system [1]. The modernization of Kazakh education involves establishing conditions for curriculum continuity, promoting continuous professional development, and enhancing the quality of higher and secondary education. This necessitates maintaining consistency and continuity throughout all educational stages to ensure a seamless progression through educational programs.

About the concept of lifelong learning, secondary education is a part of a comprehensive and integrated education system. The Republic of Kazakhstan is currently reforming its education system as well as modernizing the content of general secondary education to ensure an active and evolving structure. State compulsory standards and guidelines for secondary education in public schools were developed in the form of new curricula and programs. At the same time, higher education programs, particularly in the pedagogical field, do not take into account changes in school curricula. The low level of continuity in the context of general secondary education curricula and higher education teacher training programs creates problems for the education system as a whole and for school education in particular [2]. The development of science and technology makes new demands on university and school education [3].

The continuity principle is a didactic classification that combines a changeable structure of learning materials, patterns of content change, the linear-discrete nature of the learning process, and a combination of teaching methods aimed at resolving conflicting interests in the development of the intellectual abilities of young people in line with educational objectives [4]. The market for supplementary educational programs–study guides, learning materials, and summer programs–has grown tremendously [4]. Due to a number of historical and structural features of educational systems in developed countries, elements of relationships in schools can often act as barriers to change [5]. In order to meet the changing needs of students and many other stakeholders in education in the 21st century, education systems around the world are in the process of continuously changing paradigms in their curricula, teaching methods, management and assessment process, and other related components [6].

The development of culturally appropriate and relevant individualized education programs (IEPs) is becoming increasingly important as the student community becomes more diverse. The existing support for IEPs groups largely focuses on technical elements of educational plans, such as crafting measurable objectives. However, it offers limited assistance in creating culturally suitable and pertinent IEPs [5].

Given the recent emergence of programs to improve the quality of education, guidance for evaluating the efficiency of these programs is required. Without a systematic approach, evaluation efforts may be dispersed, lead to an excessive workload on participants, or provide useless feedback due to poor compliance with the program [7]. Evaluation of educational programs is a set of activities carried out to determine the success level of educational programs [8].

The purpose of this research is to address the significance of investigating content continuity within science disciplines in school and university curricula, specifically using the “physics” course as an example. The study also aims to identify principles governing content continuity in both school and higher education contexts for natural sciences, focusing on the “physics” course. The novelty of this study lies in its comprehensive exploration of content continuity within science disciplines in both school and university curricula, using the “physics” course as a focal point.

2. RESEACRH METHOD

The primary method in this study is system analysis, which is applied to examine the continuity of the school and university science curricula content, using the “physics” course as an example. Using the example of physical theory, the analysis of successive knowledge confirms the idea that this is not a private, non-existent feature, but an essential aspect of cognition. The continuity of scientific theories reflects the specificity of science as a particular form of social consciousness. The continuity principle performs various functions in the development of science. Thus, during the creation of new knowledge, it is used as a heuristic tool. Once a new theory has been created, it is necessary to establish formal and meaningful links between the old and new theories.

The study authors have identified essential criteria for maintaining continuity in secondary and higher teacher training, including consistent goals and content, the building of graduates’ creative orientation, adaptive educational technology utilization, alignment with labor market conditions, and the fostering of professional independence. Notably, a focused exploration of content continuity is crucial. Achieving professional education coherence hinges on maintaining content consistency across different educational levels. The integrity of continuing education is pivotal, guaranteeing the interconnectedness, consistency, and progression of educational programs. The challenge of maintaining continuity in physics education pertains to learning content cohesion, particularly in primary and secondary schools. This challenge has amplified due to evolving education methods, technological shifts, and novel result assessment approaches.

The study also included the theoretical analysis of recent scientific publications. Researchers and scholars in the field of pedagogy often consider and investigate issues related to the continuity of the school and university science curricula content, as well as analyzing methods of ensuring curriculum continuity. In recent years, foreign and domestic scholars have studied problems and ways of improving the continuity of the content of school curricula and educational programs.

3. RESULTS AND DISCUSSION

The new education program provides a focus on the needs of the current generation by transferring not only a certain amount of learning materials but also by providing a system of expected outcomes. According to the updated curriculum, natural sciences, especially physics, are taught simultaneously from 7th grade. Teaching physics in the context of continuity of educational content aims at understanding initial information about the structure and properties of substance, heat, electricity, magnetism, and optical phenomena, representing a certain initial system of knowledge. The physical phenomena under consideration and the regularities of their course are already disclosed at this stage from the standpoint of the molecular kinetic theory, involving certain elements of the atom structure theory. The limitation of compulsory education in middle school has changed the structure of the entire physics course. The physics course in the middle school has thus become a two-stage one-a propaedeutic course and a basic course. Numerous propaedeutic integrative courses such as "natural science" and "environment" have emerged [9].

The syllabus of the "physics" course activities in terms of the latest learning materials contains temporal elements of the subject, sequence of topics to be studied, basics of the fundamental science theory (overview of results, overview of all creative activities from reproduction to creation), hierarchy of learning needs, emphasis on development of social activity and social skills. Continuity of physics learning material according to the knowledge level of the updated learning material. During basic lessons, students are introduced to the basic materials: "structure and properties of matter", "classification of matter", "origin and creation of matter", "processes of inanimate nature", and "processes of animate nature"; through chemical experiments and observation, students master basic skills and knowledge in physics.

The purpose of physics education is to form the basis of a scientific worldview, a holistic understanding of the world-scientific image, and the ability to observe, analyze and capture natural phenomena to solve particularly important practical tasks. The volume of the academic load in physics subject is: in the 7th-8th grades–2 hours per week, i.e., 68 hours per academic year. The content of the subject "physics" in the 7th-9th grades includes eight sections: physical quantities and measurement; mechanics; thermal physics; electricity and magnetism; geometrical optics; elements of quantum physics; fundamentals of astronomy; and modern physical picture of the world [9].

The subject "physics" in the 7th grade course deals with natural phenomena, the basic laws of physics, and the application of these laws to technology and everyday life. Particular attention is paid to the fact that physics and its laws are the core of all-natural science. In the 7th grade, students are introduced to the basic concepts in the introductory part: "atom", "matter", "physical term", "hypothesis", "experiment", "measurement", "error of measurement", "international system of units (SI)", and "scalar and vector quantities", which form the basis of physics. The quality of the physics learning experience in the 7th grade is strongly influenced by the knowledge from the 6th grade mathematics, and the 7th grade geometry and algebra. The subject's "physics" and "chemistry" teach many common concepts: "atom", "molecule", "physical and chemical phenomena", "mass", and "aggregate states of matter". Therefore, when studying the same topics, it is necessary to achieve the same interpretation of these concepts. Knowledge from the biology field extends knowledge of the operation parameters of physical laws and contributes to the student's understanding of the nature essence. The consideration of issues that relate to the use of physical terms and concepts in biology serves the same purposes. One of the primary features of physics lessons is that pupils learn how to determine physical quantities experimentally, reproduce the experiment, use the available instruments, take the readings, and analyze the results. In the 8th grade physics course, there are three sections: "thermal physics", "electricity and magnetism", and "geometric optics". It is worth paying attention to the content of the theoretical material, which is largely aimed at demonstrating the significance of natural sciences in human life, assessing the achievements of science, and developing an awareness of the environmental problems arising as a result of scientific and technological progress.

The fact that such subjects as "physics" and "chemistry" are complementary sciences is undeniable. General concepts of physics and chemistry include the following: the essence of matter, mass, weight, energy and the law of conservation of energy, electricity, conservation of electric charge, molecular-kinetic, and electron theory. In physics lessons, special attention should be paid to the involvement of the local component: the achievements of local scientists in various fields of technology, medicine, agriculture, industry, and energy. For instance, when developing science projects by 8th grade students, it is recommended to pay attention to the following learning objectives, which have practical relevance in everyday and social life: to give examples of the application of heat transfer in everyday life and technology; to give examples of the adaptation of living organisms to different temperatures; to describe the transformation of energy in heat machines; to assess the impact of heat machines on environmental conditions; to give examples of electric energy production in the world and Kazakhstan.

The main objectives of the subject in the 10th and 11th grades are: i) learning about the fundamental physical laws and principles that underpin the modern physical world picture, as well as the methods of scientific knowledge of nature; ii) developing students' and pupils' intellectual, informational, communicative, and reflective learning culture and skills in performing physical experiments and investigations; iii) fostering a responsible attitude to learning and research activities; and iv) applying the acquired knowledge for careful and responsible use of natural resources and protection of the environment, ensuring the safety of human life and society [9].

A comparison of the content of the updated model curriculum and the model curriculum for the general secondary education of the "physics" discipline for grades 10 to 11 of the general secondary education is presented in Table 1. The curriculum for the subject "physics" in the 10th grade begins with mechanics, including chapters on “kinematics”, “dynamics”, and “statics”, the content of which is intended to continue to deepen knowledge and develop skills learned in the 7th and 9th grades. The primary purpose of studying the topic “fundamentals of kinematics” in the 9th grade physics course is to investigate a simple form of matter motion–mechanical motion, based on the laws of classical mechanics. Learning about the motion of a body or a material point means understanding how its position changes over time. The main task is to find the position of the body at each point in time.

Table 1. Comparison of the content of the existing model curriculum for general secondary education and the updated model curriculum

Model curriculum for general secondary education (2013)		Structure of the updated model curriculum (2017)	
Section	Subsection	Section	Subsection
Mechanics	Kinematics	Mechanics	Kinematics
	Dynamics		Dynamics
	Movement of liquids and gases		Statics
			Conservation laws
			Mechanics of liquids and gases
Molecular physics	Foundations of the molecular-kinetic theory	Thermal physics	Foundations of the molecular-kinetic theory of gases
	Gas laws		Gas laws
	Fundamentals of thermodynamics		Fundamentals of thermodynamics
	Fluids and solids		Fluids and solids
Electrodynamics	Electrostatics	Electricity and magnetism	Electrostatics
	The laws of direct electric current		Direct current
	Magnetic field		Electric current in various environments
	Electromagnetic induction		Magnetic field
	Oscillating circuit		Electromagnetic induction
	Electromagnetic waves and the physical foundations of radio engineering	Electromagnetic oscillations	Mechanical oscillations
	Light waves and optical instruments		Electromagnetic oscillations
	Elements of the special theory of relativity		Alternating current
		Electromagnetic waves	Wave process
		Optics	Wave optics
			Geometric optics
		Elements of relativity theory	Elements of relativity theory
Quantum physics	Light quanta	Quantum physics	Atomic and quantum physics
	Atom physics		Physics of atomic nucleus
	Physics of atomic nucleus	Nanotechnology and nanomaterials	Nanotechnology and nanomaterials
	Elementary particles of the universe	Cosmology	Cosmology

The main purpose of studying the “fundamentals of dynamics” section can be defined as providing students with an established understanding of Newton’s laws of motion. The basis of the doctrine is formed by studies of the motion of bodies and the Galileo and Newton experiments. Applied methods and the use of Newton’s laws to solve classical problems are presented as corollaries of the doctrine. Newton’s laws of motion, which were introduced in the chapter on “laws of dynamics”, are considered to be the leading laws of traditional mechanics. Issac Newton created a clear concept of the mechanical movement of bodies and established the laws of mechanics (Newton’s three laws and the law of universal gravitation), which in combination enable a logical description of all mechanical movements occurring both on earth and in the solar system. Newton's laws can be applied to virtually all movements of celestial objects, to the movement of man-made objects in space, satellites, all machines, and vehicles. These laws have significant cognitive, worldview, and educational value. As a consequence, a great deal of time is devoted to this topic at school.

The content of this chapter is difficult for students to grasp, so the presentation of the principles of dynamics requires a creative explanation by the teacher. The students were introduced to questions related to the study of the laws of dynamics when studying the topic “kinematics”. In this section, students can learn about the later development of the idea of a reference frame and the relativity of motion. It should be noted that although students can reproduce the correct formulations of Newton’s laws, they do not always understand and explain them correctly. A formal understanding of Newton’s laws can be found in answering questions that involve the correct use of theoretical knowledge. While studying the principles relating to the conservation of momentum and energy, students should thoroughly study other conservation laws in the natural sciences.

The initial concepts of physical phenomena and the measurement of physical quantities enable students to understand the qualities of a researcher as described in the chapter on “I am a researcher” and “physics of nature” within the subject of “natural science”. They are also familiar with physical phenomena in the 7th grade with the phenomena of nature discussed in the chapter "physics-science of nature" and physical quantities, the definition of the scale division value of instruments and their measurement, the scale of instruments, and the instrumental errors of measurement. The students distinguish between types of energy, and energy transformation and are aware of the need to save energy. This section expands the student's understanding and explains the results of their previous observations based on the partial and kinetic theory of matter. The students learn the equations of gas states and concepts in this section and consider the absolute temperature scale.

Students in the 8th grade are introduced to several ways of using electricity in everyday life and learning about them. This section should teach them basic concepts such as electric field, magnetic field, charge, current, and potential difference, as these are essential elements for further study (10th grade). These concepts are expanded with the study of the electric field and electric power in the 10th grade. The basic content of the 11th grade "physics" subject aims to develop students' understanding of physics as a science of nature, methods, and methodology of scientific cognition, and the role and interrelation of theory and experiment in the cognitive process. The curriculum in the updated subject content is based on the spiral principle, which means that most of the didactic objectives are mixed in each grade with a gradual increase in the complexity of the material (during the school year and in the following grades). Table 2 presents the section titles of the curriculum, showing the continuity of the topics based on the spiral principle.

Table 2. The section titles of the syllabus for the "physics" subject in the middle and high school, showing the continuity of the topics according to the spiral principle

Grades 7-9	Grades 10-11	Continuity
1. "Physical quantities and their measurement"	1. "Mechanics"	Educational objectives and topics change with each year of study, and the complexity of the material increases.
2. "Mechanics"	2. "Thermal physics"	
3. "Thermal physics"	3. "Electricity and magnetism"	
4. "Electricity and magnetism"	4. "Electromagnetic oscillations"	
5. Light phenomena "Geometric optics"	5. "Electromagnetic waves"	
6. "Elements of quantum physics"	6. "Optics"	
7. "Fundamentals of astronomy"	7. "Elements of relativity theory"	
8. "Modern physical picture of the world"	8. "Quantum physics"	
	9. "Nanotechnology and nanomaterials"	
	10. "Cosmology"	

Research professionalism is one of the most essential criteria for future success in the chosen field of expertise, since exploring difficulties, testing hypotheses, and suggesting new methodologies are universal operations for solving all kinds of tasks. A person with research competence can change problematic circumstances (make them non-problematic), or adapt to them. For instance, since anyone faces a variety of domestic, professional, and general tasks every day, mastering the ways of learning about the world around them is rather relevant. The new system takes into account the deepening of all the abilities provided for in Bloom's taxonomy. The deepening and expansion of abilities from lower to higher levels according to the taxonomic ranking is reflected in the formulation of the learning objectives and is realized through the activity of the students during the lesson [10], [11].

Physical experiences play an important role in the content of educational literature. Students gain fresh knowledge and master skills through practical work. Therewith, the following laboratory and practical works are integrated into the learning system: "investigation of the condition for current formation in electrolytes"; "determination of the number of turns in transformer windings"; "observation of light polarization"; "determination of light wavelength with a diffraction grating"; "determination of the refractive index of glass"; and "determination of the half-life". When learning chemistry, students make discoveries based on the data they have acquired, autonomously finding patterns of phenomena and processes in nature. The continuity of major subjects in upper secondary schools enables students to prepare for university studies in the fields of science and technology. Consequently, the teaching process should not only focus on the compilation of stable subject knowledge, but also students' understanding of the cognition formation process, its logic and structure, and the formation of metacognition as the basis for a scientific understanding of the world [12], [13].

The idea of continuity is most fully revealed through the concepts of correlation of absolute and relative truth and the essence of different orders. At the beginning of the 20th century, in solving specific physical tasks in the theory of relativity and quantum mechanics, essentially the same idea was used by Einstein and Bohr, who called it the "correspondence principle" [14]–[16]. Continuity of education is considered by Abirov [17] as a phenomenon that determines the potential qualitative growth of students' creativity. Continuous quality improvement in higher education involves a set of systematic actions aimed at immediate and positive change [18], [19]. The primary purpose of the education system should not only provide future generations with opportunities for personal growth but also to help them learn lessons from activities carried out by non-governmental organizations and educational centers that seek to improve the quality of education in general [20], [21]. Curricula are usually designed to achieve specific learning outcomes, the success of which can be assessed by accreditation bodies, for instance in the fields of engineering, medicine, law, and business [20], [22]–[24].

Study by Bada and Jita [25] focused on students' perceptions of their physics teachers, specifically regarding the use of instructional materials, teaching methods, and classroom management. The study highlights the importance of students' viewpoints in evaluating teachers' classroom practices. It suggests that students' opinions can significantly influence teaching and learning outcomes. The study employs a quantitative approach by using a researcher-designed questionnaire to collect data from a sample of physics students in Nigeria [25]. The analysis involves descriptive and inferential statistics to assess teachers' performance in different areas. Integrating the insights from both studies, the connection between curriculum updates and students' perceptions becomes evident. The study on curriculum updates highlights the goals of fostering critical thinking, creativity, and societal contribution through educational changes, while the investigation into students' perceptions of physics teachers' practices provides valuable feedback on the practical implementation of these updates.

In turn, Zulherman *et al*. [26] discussed a research study that evaluated the adoption of e-learning in higher education and its impact on students. The research aimed to assess the validity and reliability of the model's items and to test various hypotheses. The results of the study indicated that e-learning adoption enhanced students' motivation, confidence, and knowledge. By integrating the findings on successful teaching methods, teacher training, and continuing education development from Zulherman *et al*. [26], it is possible to develop e-learning approaches that not only improve subject knowledge but also increase students' motivation, confidence and self-efficacy.

The study by Wenno *et al.* [27] aimed to enhance students' critical thinking skills through a scientific approach to teaching physics. Learning materials such as lesson plans, teaching materials, and physics test instruments are developed using a 4D model (define, design, develop, and deploy). The process involves validation by experts, practitioners, limited trials, and piloting. Various data collection instruments are used, including validation sheets, test instruments, observation sheets, and questionnaires. The curriculum revitalization proposed in this study to develop adaptable and critical thinkers can incorporate scientifically developed teaching tools from the work of Wenno *et al.* [27]. Such integration not only enriches the curriculum but also helps in teacher training and implementation by providing effective resources.

Research by Mafarja *et al*. [28] focused on the impact of reciprocal teaching strategies on students' academic self-concepts in physics. Reciprocal teaching involves collaborative dialogues between teachers and students using techniques such as predictions, question generation, and clarifications. The study involved an experimental group that learned physics through interactive teaching and a control group that used traditional teaching methods. The study suggests integrating reciprocal teaching into secondary school physics classes and providing training for teachers to implement this strategy effectively. Incorporating a collaborative, peer-to-peer learning approach into a revitalized curriculum can foster the desired qualities while meeting the need for teacher training and lifelong learning [29]. By combining these ideas, educators can create a comprehensive and effective learning environment that promotes the holistic development of students and prepares them for success in a rapidly changing world.

Nzomo *et al.* [30] examined the use of inquiry-based learning (IBL) in teaching chemistry to influence students' attitudes and academic performance. They focus on secondary school students, suggesting a specific age group and educational level. Using a correlational research design, the study finds that teachers employ IBL weekly, and students generally exhibit positive attitudes toward chemistry. The research highlights a significant correlation between IBL and positive chemistry attitudes. The teacher preparation methods used in the author's study can be expanded to include IBL methods that encourage collaboration and cross-curricular innovation. The combination of these ideas can lead to a holistic approach to science education that fosters well-rounded students with higher attitudes toward physics and chemistry, critical thinking skills, and a commitment to lifelong learning.

These studies hold significant potential for mutual enrichment and the development of a more effective and holistic approach to teaching and learning. They collectively emphasize the importance of research competence, continuity in education, curriculum updates, and innovative teaching methods. By integrating their findings, educators can enhance teaching strategies, inspire curriculum improvements, and nurture students' attitudes and skills.

4. CONCLUSION

It can be concluded that updating the content of school and university curricula has been discussed in terms of the natural science subject "physics", considering the rules of continuity and based on municipal priorities. It is performed with the aim of learning, educating and developing a creative, critical-thinking and well-performing individual in a rapidly changing world, able to deepen his or her own knowledge and degree of cultural awareness every day, and able to benefit society. The developed abstract and methodological bases for ensuring the continuity of educational programs of the higher pedagogical and general secondary education will enable graduates of higher pedagogical specialties and of natural science courses to have a thorough understanding of the content of subjects studied in secondary educational institutions on the basis of the current requirements of the updated educational content.

In order to ensure continuity in the curriculum when renewing the content of youth education, training teachers for these changes through their professional and pedagogical education is an important area of focus. The readiness to implement lifelong learning in school and university is a complex dynamically integrated system formation that operates at different levels of participation in contact with the subject of learning activity–the student, reflecting the overall personal orientation of the teacher in accordance with their position and an evaluation of the teacher's personality traits. An important place in the study of scientific disciplines is occupied by the organization of study and research activities for modern high school students, as well as for university students, with the aim of fostering their sustained cognitive interest. The purpose of the "physics" course for students of 10th-11th grades of secondary schools in the updated content represents the process of shaping the students' scientific worldview, holistic perception of the natural-science image of the surrounding world, the ability to observe, write, and analyze the phenomena of nature in solving practical problems which are important in life. The in-depth course content presents the possibility of planning and conducting experiments aimed at identifying empirical dependencies through the collection and analysis of experimental results.

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