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Teaching Students Interdisciplinary Knowledge through Compilation of Differential Models within the Framework of Course Projects

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Abstract: In the process of educating future teachers of mathematics to build differential models, there are significant difficulties associated with the lack of natural science knowledge among students, the inability to represent the task in the context of interdisciplinary connections and functional relationships. Thus, the need to study and solve these problems, their theoretical and practical significance in the formation of interdisciplinary knowledge among future mathematics teachers determines the relevance of the research topic. The following article proposes an algorithm for the implementation of interdisciplinary learning, the compilation of differential models on the example of the implementation of an integrated course project by students – future teachers of mathematics, chemistry and physics. In 2020, an experimental study was conducted on the basis of two universities of the Republic of Kazakhstan. The study used empirical research methods: written work, questionnaires, conversations with teachers and future teachers. Data analysis revealed that 87% of students and 80% of teachers lacked knowledge and skills to create mathematical models and establish interdisciplinary connections. In addition, in the process of teaching students to compile differential models, there are difficulties in establishing dependencies between interdisciplinary concepts, in compiling and solving differential models. An experimental study showed that higher education teachers face the following learning issues: the development of a new content of mathematical disciplines aimed at creating the ability of future teachers to compose mathematical models, at ameliorating their mathematical thinking, interdisciplinary knowledge; development of a methodology for teaching future teachers of mathematics interdisciplinary knowledge, to compiling differential models.

Keywords: Applied problems; Higher education; Interdisciplinary thinking; Math; Methodology

1. Introduction

To determine the technological suitability of many science-intensive processes, it becomes necessary to conduct the most complex tests. For reasons of economic feasibility, or technical safety, or due to the lack of technological capabilities, conducting such tests is very often proved to be barely impossible. To solve this problem, one usually resorts to the compilation and study of mathematical models of the phenomena and processes under consideration.

A mathematical model is a mathematical description of a process or a real phenomenon using various functional relationships. The study of the compiled model allows authors to describe the main characteristics of the phenomenon under consideration. To compile an appropriate mathematical model the interdisciplinary knowledge, with the help of which the phenomenon under study is described, is used. In addition, in the modern organisation of technological processes of production, the formation of interdisciplinary thinking among specialists is of particular importance (PISA 2021).

In this regard, in the global educational space, the content of secondary education is increasingly becoming an applied element (The Future of Education and skills, Education 2030, 2018). Consequently, such an orientation of the content of secondary education determines the inclusion of interdisciplinary elective disciplines in university educational programs for the training of future teachers. Thus, the formation and development of skills of future teachers of interdisciplinary knowledge and skills through the construction of mathematical models is of theoretical interest and is important in practical applications.

The updated content of secondary mathematical education in the Republic of Kazakhstan is aimed at practice-oriented education, which involves the introduction of interdisciplinary education, the comprehensive development of the personality of students through the solution of applied problems. However, the idea of introducing interdisciplinary learning in the education system of the Republic of Kazakhstan and in many countries of the world remains poorly implemented (Zhan et al., 2017). Practice has shown that the main reason for the poor implementation of interdisciplinary education in schools is the narrow specialisation of school teachers. Such fundamental difficulties in implementing the updated program show that the main purpose of these programs should be directed towards the formation of interdisciplinary knowledge among future teachers, improving the methodological training of mathematics teachers in the context of the formation of interdisciplinary knowledge.

An analysis of the educational programs of universities, the practical work of teachers of higher mathematics in the Republic of Kazakhstan shows that in the process of organising mathematics teaching, certain problems that reduce the effectiveness of the formation of interdisciplinary knowledge among future teachers of mathematics exist. These problems are also manifested to some extent in the global educational space in the form of a lack of unified approaches in determining the readiness of future mathematics teachers for interdisciplinary teaching of schoolchildren, in the form of underdeveloped technologies and methodology for interdisciplinary, integrated future teachers, in the form of teachers' lack of natural science knowledge (Stentoft, 2017).

Interdisciplinary learning is clearly shown in teaching students how to compile differential models, which allows to identify internal relationships between different interdisciplinary concepts, ensures the effectiveness of the process of teaching future specialists interdisciplinary knowledge, changes the structure and logic of the presentation of educational materials, changes the scientific and applied orientation of elective disciplines. At the same time, in the process of educating future teachers of mathematics to build differential models, there are significant difficulties associated with the lack of natural science knowledge among students, the inability to represent the task in the context of interdisciplinary connections and functional relationships.

Thus, the need to study and solve these problems, their theoretical and practical significance in the formation of interdisciplinary knowledge among future mathematics teachers determines the relevance of the research topic.

2. Literature review

To solve the technological problems of production and the tasks of the economy, interdisciplinary research and development teams are increasingly being created, which ensure their competitiveness and become a higher priority in solving their personnel tasks (Dirsch-Weigand et al., 2018).

In addition, the production tasks solved by workers are becoming more technological and complex, the solution of which requires interdisciplinary knowledge and skills. In production, interdisciplinary competencies of workers are defined as the ability to solve problems, work in a team, innovate, and think critically, which are formed when future workers are taught interdisciplinary disciplines (Borrego & Newswander, 2010). In this regard, a high school graduate must have natural scientific knowledge, be able to apply it in solving real practical problems of the surrounding world, which would meet the requirements of the employers. Therefore, training that forms the professional competence of future teachers should be aimed at the formation and development of their interdisciplinary competence.

Many researchers characterise problem-based learning (PBL), project-based learning (PjBL) as effective approaches that implement interdisciplinary learning (Stentoft, 2017; Dirsch-Weigand et al., 2018). Researchers Brassler & Dettmers (2017), based on the analysis and application of the basic principles of interdisciplinary learning in teaching, argue that problem-based interdisciplinary learning (iPBL) is more effective in contrast to project-based interdisciplinary learning (iPjBL). The article by Boeren (2017) highlights the methodological problems that arise when working on interdisciplinary modules, and discusses a new interdisciplinary theory of learning. Braskén et al (2020) describes the experience of implementing interdisciplinary curricula in Finnish schools, H. Wang et al (2020) explored the issues of defining interdisciplinary collaboration based on high school teacher beliefs and STEM integration practices.

Comparing the results of these and other studies on interdisciplinary learning, European practitioners have created separate integrated disciplines that have shown their effectiveness in shaping the knowledge and practical skills of schoolchildren. The content of these courses includes educational materials from two or more scientific fields: mathematics, physics, music, chemistry, biology, literature, etc. (Antikainen & Luukkainen, 2008; Braskén et al., 2020)

National research centers and various professional communities in America propose to develop a new educational concept focused on the integration of technology, engineering and various areas of the natural sciences (Wang et al., 2020). However, analysis of research results (Spelt et al., 2017; Rienties & Heliot, 2018; Zhan et al., 2017; Neminska, 2018; Lattuca et al., 2018) show that interdisciplinary learning does not come on its own in any interdisciplinary module.

In addition, when teaching students interdisciplinary knowledge, such practical difficulties arise (Stentoft, 2017; Zhan et al., 2017), as: determining the necessary natural science knowledge to understand the problem under consideration; drawing up training and educational programs focused on interdisciplinary learning; lack of specific models of interdisciplinary learning; conscious cooperation of teachers in interdisciplinary training, who teach only mono-disciplines; students' lack of motivation to acquire interdisciplinary knowledge. Thus, there was a need for a deep study of an interdisciplinary or integrated teaching approach in the context of world educational programs and for the wide application of this approach in Kazakhstani education.

In this regard, the requirements for the professional qualities of future teachers have recently changed in Kazakhstani education. The students must know the content of education, but must also be able to think critically, possess the skills of research work, and apply the acquired interdisciplinary knowledge in solving practical problems (State program for the development of education and science in the Republic of Kazakhstan for 2020-2025, 2009). All these qualities should be formed and developed at the university when future teachers are trained in mathematical and natural science disciplines.

One of the approaches to the formation of such professional qualities is the training of future teachers in the construction of mathematical models, in particular, differential models. For example, Brandi & Garcia (2017) offer students practical tasks for compiling differential models that include several concepts that allow you to compare the resulting differential models, motivate students to learn. Neves (2011) explores the issues of teaching students to build a specific differential model that describes the spatial specificity of cellular reactions.

However, the analysis showed that the issues of teaching students to build differential models in the context of the formation of interdisciplinary knowledge among students remains little studied. For example, Castillo-Garsow (2013) found that even the simplest concept of exponential growth in school mathematics remains largely unexplored. Thus, teaching students to build differential models in the context of the formation of interdisciplinary thinking, the practice of organising interdisciplinary learning is of scientific and practical interest to many researchers.

3. Materials and Methods

In the context of the updated content of secondary education, the system of higher pedagogical education in the Republic of Kazakhstan is expected to train such teachers of mathematics who are engaged not only in teaching mathematics, but also successfully implement integrated education, acting as managers of interdisciplinary teaching.

In order to identify the formation of skills in future teachers to compile mathematical models, interdisciplinary knowledge in 2020, an experimental study was conducted on the basis of two universities of the Republic of Kazakhstan. The study used empirical research methods: written work, questionnaires, conversations with teachers (15 men) and future teachers (102 students).

In this regard, teachers of higher education are faced with some important issues: the development of a new content of mathematical disciplines aimed at developing the skills of future teachers to compose mathematical models, the development of interdisciplinary knowledge, for the creation of a methodology for teaching future teachers of mathematics interdisciplinary knowledge. The answers to these questions should be of a generalised nature, and may be applicable in the construction of a differential model for any relevant phenomenon of the surrounding world.

In addition, during the research, based on the joint course project of future teachers of mathematics, chemistry and physics, an algorithm for the implementation of interdisciplinary training was modelled. Its structure consists of 5 stages. In particular, presentations of the problem situation; formation of motivation and challenge; specification of project topics; compilation of knowledge baggage; formation of a problem-solving algorithm. The analysis method was applied to study the principles on which the simulated scheme is based. The conditions of qualitative understanding of interdisciplinary knowledge were analysed and a new integrated discipline "Differential Equations in Applied Problems" was developed based on them.

At the end of the study, an additional experiment was conducted, the participants of which were 34 students of the 1st-4th years of the Faculty of Mathematics. Its goal was to determine the interdisciplinary knowledge of the entrants due to the compilation of differential models.

The research was conducted in three stages. At first, the theoretical foundations related to the interdisciplinary training of future mathematics teachers were revealed. In addition, the main principles of integrated education are revealed. At the second stage, practical tasks are studied, which involve the student's use of knowledge from various fields. A discussion was also held, which consisted in comparing the results obtained by the author with the positions of other scientists. At the third stage, the main provisions identified in the research were determined in the conclusions, together with the proposals on priority directions for the continuation of this scientific work.

The sampling method involved stratified random sampling, dividing participants into groups based on being teachers and students. Instruments used for data collection were written tests, questionnaires, and interviews. The written tests helped evaluate the understanding and application of mathematical models. Questionnaires collected insights on the perceptions and experiences with interdisciplinary learning. Interviews with teachers gathered deeper understanding of their experiences and challenges. Data from the written tests were analysed quantitatively, questionnaire data were examined using descriptive statistics and thematic analysis, and interview data were analysed through thematic analysis to identify common themes.

4. Results

It is known that interdisciplinary learning cannot be effectively implemented using only separate learning methods (Rienties & Heliot, 2018). Only a systematic approach to the learning process ensures the formation of students' interdisciplinary knowledge, practical skills to apply the acquired knowledge in solving applied problems.

In this regard, this article will illustrate the scheme of using interdisciplinary learning on the example of a joint course project by students – future teachers of mathematics, chemistry and physics. This project is aimed at the formation of critical thinking, the systematisation and application of acquired knowledge in higher mathematics, physics and chemical kinetics, teaching students how to compile differential models, which is oriented towards interdisciplinary learning. This approach, obviously, ensures the development of students' thinking, cognitive, and research abilities.

One of the approaches to the formation of these abilities of students is problem-based learning (PBL). The proposed method of problem-oriented teaching of future teachers of mathematics consists of the following stages: presentation of a problem situation; formation of students' motivation and challenge through the formation of awareness in the acquisition of professional knowledge and skills; concretization of the topic of projects by creating the authenticity of the project; compiling a baggage of necessary knowledge; drawing up an algorithm for solving the problem.

Presentation of the problem situation. At the early stage, students are presented with semi-structured project topics: “Compilation of a mathematical model for changing the current strength in an electrical circuit”; "Compilation of a mathematical model for changing the concentration of a reversible reaction". After getting acquainted with the topics, the students are introduced to the executors of the project (two students each from the OP "Mathematics", "Physics", "Chemistry").

Formation of students' motivation and challenge through the formation of awareness in the acquisition of professional knowledge and skills. In order to form educational and cognitive motivation and challenge future teachers of mathematics, physics, chemistry, the teacher introduces students to the essence of the problem. If the student sees the proposed task as an opportunity to apply the acquired knowledge in their daily activities, then the student has a need and interest in solving it. At this stage, each student is convinced that they do not have certain knowledge to understand and solve these projects. As a result, students have a desire to eliminate gaps in their knowledge.

Data analysis revealed that 87% of students and 80% of teachers lacked the ability to create mathematical models, interdisciplinary knowledge. The study showed that when teaching students to compile differential models, focused on interdisciplinary learning, difficulties arose in establishing dependencies between different disciplinary concepts, compiling and solving differential models.

After analysing the data on the conversations and questionnaires, the study found that teachers and students faced significant challenges when trying to integrate knowledge from various disciplines. It was noted that 70% of students found difficulty in understanding the interplay between different subjects in creating mathematical models, indicating a gap in their interdisciplinary knowledge. On the teachers' part, many mentioned they often struggle to adequately explain the connections between different scientific concepts when teaching differential model creation. About 75% of teachers expressed a need for a more structured methodology and resources to effectively instil interdisciplinary knowledge in their teaching practice. In relation to the joint course project involving future teachers of mathematics, chemistry, and physics, the feedback received through questionnaires and conversations reflected that the project was beneficial in demonstrating the applicability of mathematical models across various disciplines. However, difficulties were still observed in the practical application stage, specifically in the formation of the problem-solving algorithm. These results highlight the need for improved curricula and pedagogical approaches to equip future teachers with the necessary skills and knowledge for interdisciplinary teaching, particularly in the creation of mathematical models.

Concretization of the theme of projects by creating the authenticity of the project. To make the problem concrete, determine the significance of the project, self-expression and the allocation of a common problem by students, the first task was proposed.

Task 1. Formulate in writing reasonable answers to the following questions (deadline: 1-week). For what purpose were such topics proposed for implementation? Is it possible to specify the proposed topics of these projects more concretely? What knowledge and skills are needed to carry out these projects?

All students' answers were formulated and substantiated on the basis of information and educational resources. Based on the results of the discussion of the students' answers to these questions, more specific problems were formulated: "Compilation of a differential model for changing the current strength in an electrical circuit"; "Compilation of a differential model for the change in the concentration of reactants in a reversible first-order reaction".

After that, the students were asked the question: what is common between the two projects under consideration? Discussion of the students' answers to this question, leading additional questions of the teacher, made it possible to formulate the final theme of the project "Formation of future teachers of interdisciplinary knowledge in the context of their training in compiling differential models" and determined the significance of this project: the creation of an interdisciplinary module of a new integrated teaching aid for future teachers.

Drawing up a baggage of knowledge. At this stage, the students were offered the 2nd task (duration: 2 weeks): Compile a “Knowledge Table” for this project, which consists of four columns. In the first column, students write out questions, in the second and third columns they indicate knowledge and ignorance of the corresponding question marked “I know” and “I need to find out”, in the fourth column they write down extended answers to questions, interpreting them from one form of presentation to another. Work according to the table is carried out throughout the entire project. The table is adjusted and updated as the project progresses. The compilation of this table contributes to the development of critical thinking among students, the formation of interdisciplinary knowledge, teaching students to design differential models, compiling an algorithm for project implementation, monitoring the acquired knowledge of students and controlling the implementation of the project.

Drawing up an algorithm for solving the problem. An analysis of works related to interdisciplinary learning (Brassler & Dettmers, 2017; Stentoft, 2017; Spelt et al., 2017; Braskén et al., 2020), made it possible to identify an algorithm for teaching future teachers of mathematics to build differential model of real processes, in the context of the formation of interdisciplinary knowledge: familiarisation with the content of the task; drawing up tables of knowledge; consideration and discussion of the knowledge written out by students that are directly related to the nature of the task being studied; the choice of an independent variable and the function of this variable that authors want to find; the expression of all the quantities appearing in the condition of the task, through the independent variable, the desired function and its derivatives; determination of the law to which the given task is subject. Drawing up a differential model for this problem; determination of the initial or boundary conditions; construction of a solution or an integral of the composed differential equation; studying the behaviour of the solution of the constructed differential model. Revealing the practical meaning of the found solution. Interpretation of a particular solution.

Familiarisation of students with the content of the task. The problem of a reversible first-order chemical reaction. Let two chemical reactions take place in the system: direct A B (rate constant k_1) and reverse reaction B A (rate constant k_{-1}). Let at the initial moment of time t = 0 the concentration of the substance A is: $[A]_0 = a$, the concentration of the substance B is: $[B]_0 = b$. It is required to determine the dependence of concentration [A] and [B] on time *t*.

After familiarising students with the content of the problem under consideration, they are invited to compile a table of interdisciplinary knowledge that is directly related to the nature of the problem under study.

Consideration and discussion written out by students of the knowledge that is described in the table of knowledge: in a reversible first-order chemical reaction, the active mass or concentration of the reactant is described by the number of moles of this substance per unit volume; in a chemical reaction, a substance with a decreasing concentration is called a starting substance or a reactant, a substance in which the concentration has a positive increment is called a product; in a forward reaction, reactants are converted to products, and in a reverse reaction, products are converted to reactants; in a reversible reaction, both reactions – direct and reverse, proceed simultaneously; the rate of the reversible reaction A↔ B can be monitored by consumption (partially by accumulation) of reactant A, or by accumulation (partially by consumption) of product B; the rate at which a new substance is formed is called the rate of a chemical reaction.

If the value Δc expresses change in the amount of product *C* formed over a short period of time Δt, then the ratio $\frac{\Delta c}{\Delta t}$ in the ongoing reaction determines the average rate of formation of product *C*. The limit of this ratio determines the derivative $\lim_{n\to\infty}\frac{\Delta c}{\Delta t} = \frac{dc}{dt} = \dot{c}(t)$, which expresses the rate of formation of product *C* at time *t*.

In this case, the derivative $\dot{c}(t)$ is called the rate of the ongoing chemical reaction, which expresses the change in the concentration of reacting substances per unit time with a constant volume of the system.

The choice of an independent variable and the function of this variable that authors want to find. As a dependent variable x, authors take the degree of completeness of the reaction. The degree of completeness of the reaction is a value that characterises the completeness of the course of a chemical reaction. Then, for a reversible reaction, the variable $x = x(t)$ expresses the decrease in the concentration of substance and the increase in the concentration of substance B:

$$[A] = a - x, [B] = b + x. \quad (1)$$

The expression of all the quantities appearing in the condition of the task, through the independent variable, the desired function and its derivatives. The rate of the forward reaction, i.e., the rate of decrease in concentration [A], is proportional to the concentration itself [A] and is defined as $v_{dir} = k_1$ [A], and the reverse reaction as $v_{rev} = k_{-1}$ [B]. Then the total rate vgen change in the concentration of a substance [A], per unit time is determined by the difference:

$$v_{gen} = v_{dir} - v_{rev} = k_1[A] - k_{-1}[B]. \quad (2)$$

On the other hand, the total rate of change in the concentration of a substance [A] per unit time is also determined by the derivative $-\frac{d[A]}{dt}$.

Determination of the law to which the given task is subject. Drawing up a differential model for this problem. Taking into account the fact that the total rate v_{gen} of change in the concentration of a substance [A] per unit time is determined by $V_{gen} = k_1[A] - k_{-1}[B]$ and the derivative:

$$v_{gen} = k_1[A] - k_{-1}[B] \quad (3)$$

we obtain:

$$-\frac{d[A]}{dt} = k_1[A] - k_{-1}[B]. \quad (4)$$

Using (1), from (4), authors find:

$$\frac{dx}{dt} = k_1(a - x) - k_{-1}(b + x). \quad (5)$$

From here, authors obtain an equation with separable variables:

$$\frac{dx}{dt} = -(k_1 + k_{-1})x + k_1 a - k_{-1} b \quad (6)$$

Definition of the initial condition. To uniquely determine the solution of equation (6), authors set the initial condition, which authors determine from (1), taking into account the fact that the concentration of substance at the initial time $t = 0$ is equal to $[A]_0 = a$:

$$x(0) = 0 \quad (7)$$

Before solving problem (6), (7), students independently write out and discuss the algorithm for finding a solution to a differential equation with separable variables.

Construction of a solution or an integral of the composed differential equation. Solving problem (6), (7), authors obtain:

$$x = \frac{k_1 a - k_{-1} b}{k_1 + k_{-1}} \left(1 - e^{-(k_1 + k_{-1})t}\right) \quad (8)$$

Studying the behaviour of the solution of the constructed differential model. Revealing the practical meaning of the found solution. Interpretation of a particular solution. The formula we're dealing with is not just a matter of plugging values into a known equation but rather serves as a tool that lets us understand complex phenomena. The differential equation is derived from the principles of chemical reaction rates, which in turn are fundamentally tied to the concept of concentration changes in a reversible reaction. We choose the degree of completeness of the reaction as our dependent variable and express it as x(t), capturing the decrease in concentration of substance A and increase in substance B over time. Understanding the behaviour of this solution has practical significance. In the context of the teaching of mathematics, it exemplifies how mathematical models can encapsulate real-world phenomena, fostering interdisciplinary knowledge. It aids in bridging the gap between abstract mathematical theory and concrete applications in chemistry and biology. The solution's interpretation helps students visualise the progressive changes in reactant and product concentrations, thus demonstrating the value of mathematics in understanding and predicting real-world dynamics.

From (8), as $t \to +\infty$, authors will have:

$$x_\infty = \frac{k_1 a - k_{-1} b}{k_1 + k_{-1}} \tag{9}$$

Therefore, at $t \to +\infty$ the system approaches the state of equilibrium. The physicochemical meaning of the constant x_∞ can be characterised from the analysis (9): the value x_∞ expresses the amount of the substance corresponding to the change in the variable *x* from the beginning of the reaction to reaching the equilibrium state.

Substituting (9) into (1), authors obtain

$$[A] = a - \frac{k_1 a - k_{-1} b}{k_1 + k_{-1}} \left(1 - e^{-(k_1 + k_{-1})t}\right) = \frac{k_{-1}}{k_1 + k_{-1}}(a + b) + \frac{k_1 a - k_{-1} b}{k_1 + k_{-1}}\, e^{-(k_1 + k_{-1})t} \tag{10}$$

$$[B] = b + \frac{k_1 a - k_{-1} b}{k_1 + k_{-1}} \left(1 - e^{-(k_1 + k_{-1})t}\right) = \frac{k_1}{k_1 + k_{-1}}(a + b) - \frac{k_1 a - k_{-1} b}{k_1 + k_{-1}}\, e^{-(k_1 + k_{-1})t} \tag{11}$$

Hence, adding expressions (10) and (11), authors can make sure that at each moment of time t the law of conservation of masses of substances is observed:

$$[A] + [B] = a + b. \tag{12}$$

From (6) and (7) it follows that the concentration $[A]$ at $t \to +\infty$ tends exponentially to $[A]_\infty = \frac{k_{-1}(a+b)}{k_1 + k_{-1}}$, concentration $[B]$ to $[B]_\infty = \frac{k_1(a+b)}{k_1 + k_{-1}}$, and the composition of the system to equilibrium, which is characterised by the constant $K = \frac{[B]_\infty}{[A]_\infty} = \frac{k_1}{k_{-1}}$.

After a certain period of time, their speeds equalise, and a state of equilibrium occurs. Thus, the proposed algorithm for constructing a differential model provides the necessary integration, formation and systematisation of interdisciplinary knowledge of students, a methodological approach is proposed that helps to overcome the difficulties that arise when compiling differential models, when identifying the practical meaning of the solution found.

The problem of changing the current strength in the circuit. To the source of electric current (for example, a battery) with an electromotive force, equal to $E = e(t)$, that changes over time, is connected to an electrical circuit, consisting of series-connected circuit elements: inductance *(L)* and resistance *(R)*. It is required to find the law of change in the current strength over time (Figure 1).

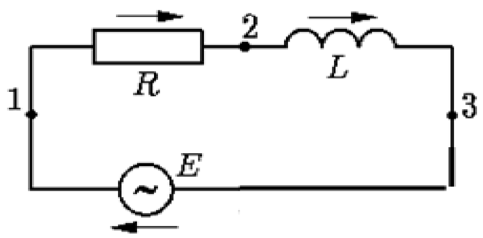

Fig. 1 The law of change in the current strength over time

At this stage, the knowledge allocated by students related to the nature of the task being studied is reproduced and discussed. For example, in order to fully understand and derive a differential model for changing the current strength in a circuit, it is necessary to acquaint future mathematics teachers with the laws of Kirchhoff and Ohm and the main elements of an electrical circuit.

As a result, students develop critical thinking based on main components and laws of the studied real processes. Obviously, the study of these laws will be effective if it is accompanied by laboratory work or animation models. To build a differential model, authors will choose the current strength as the dependent variable, and the time t as the independent variable. The potential difference, which causes a directed ordered movement of charges, is called current. Alternating current in an electrical circuit changes its magnitude and direction in a short period of time, therefore, the strength of the alternating current at time is determined as the derivative of the amount of charge with respect to time:

$$i(t) = \lim_{\Delta t \to 0} \frac{\Delta q}{\Delta t} = \frac{dq}{dt} \tag{13}$$

Now let's define the physical laws that govern the phenomenon under study. These are the laws of Kirchhoff and Ohm. According to Kirchhoff's law, the electromotive force (voltage) in an electric circuit is equal to the algebraic sum of the voltage drops across the inductance and resistance:

$$e(t) = u_L + u_R, \tag{14}$$

where the voltage drops u_R at the ends of the active section of the circuit, expressed according to Ohm's law, is related to the current $i(t)$ by the relation:

$$u_R = R \cdot i, \tag{15}$$

due to the presence of an inductance (L) in the coil, the voltage drop across the coil is proportional to the rate of change of current strength with a proportionality factor L:

$$u_L = L \cdot \frac{di}{dt}, \tag{16}$$

Then from (14), taking into account (15) and (16), a linear inhomogeneous differential equation of the first order is obtained:

$$L \cdot \frac{di}{dt} + Ri = e(t). \tag{17}$$

To uniquely determine the solution of equation (17), authors set the initial conditions in the form:

$$i = i_0 \text{ at } t = 0 \tag{18}$$

Then the solution of problem (17), (18) is given by the formula:

$$i(t) = exp\left(-\frac{R}{L}t\right)\left[i_0 + \frac{1}{L}\int_0^t e(s) exp\left(\frac{R}{L}s\right) ds\right]. \tag{19}$$

Let Then from (19) authors obtain

$$i(t) = \frac{u_0}{R} + exp\left(-\frac{R}{L}t\right)\left(i_0 - \frac{u_0}{R}\right) \tag{20}$$

As the independent variable t increases, the factor $exp\left(-\frac{R}{L}t\right)$ in (20) decreases rapidly. This means that after the expiration of some sufficiently large period of time, the process in the electrical circuit can be considered practically steady. In this case, the current will be approximately determined according to the well-known Ohm's law:

$$i = \frac{u_0}{R}. \tag{21}$$

If authors put in (14) $u_0 = 0$, then authors get the exponential function:

$$i = i_0 exp\left(-\frac{R}{L}t\right) \tag{22}$$

which describes the behaviour of the damped current when the circuit is opened. Since in (22) with increasing time *t*, the current *i* tends to zero.

This current passing in the circuit (when $u_0 = 0$ in it) under the action of the electromotive force of self-induction alone, is called the extra tripping current of the opening. The constant $\frac{L}{R}$ is called the time constant of the circuit. If in (20) authors put $i_0 = 0$, then authors get the formula for the current when the circuit is closed:

$$i = \frac{u_0}{R}\left(1 - exp\left(-\frac{R}{L}t\right)\right). \tag{23}$$

From (23) it is also seen that the current *i* after turning on the battery increases to the value $\frac{u_0}{R}$, determined by Ohm's law. Since, the current $\frac{u_0}{R}exp\left(-\frac{R}{L}t\right)$ decreases very quickly and almost soon becomes imperceptible. This current is called the short circuit extra current. Understanding and managing short circuit extra current draws from multiple scientific disciplines. Mathematics is integral for calculating potential current flows and resistances. Physics, specifically laws related to electricity and magnetism like Ohm's law and Kirchhoff's laws, provides the principles to comprehend why such currents occur. Computer science, through computer simulations, helps predict system behaviour under various conditions, including short circuits, aiding in the design of systems to mitigate potential damages.

The questions discussed are very important in cases where closing and opening quickly follow one another, for example, in telegraphy. Since in the process of compiling a differential model, future teachers of mathematics often have problem situations in establishing interdisciplinary connections, in understanding and applying certain mathematical knowledge. In conclusion, students are convinced that the same differential model describes two completely different problems from the sections of electrical engineering and chemical kinetics. The interdisciplinary knowledge in the given context arises from the need to apply mathematical concepts, specifically differential models, to two different fields - electrical engineering and chemical kinetics. Both of these fields are distinct; one deals with the design and application of electrical systems and the other with the rate of chemical reactions, yet they can be linked through the common mathematical principles that underpin them. Critical thinking is observed in several ways here. Firstly, the ability to realise that a mathematical concept can be utilised in various fields requires a holistic understanding of the subject matter, highlighting critical thinking. Additionally, the ability to draw parallels between different sectors, like telegraphy in electrical engineering and reaction rates in chemical kinetics, further showcases the application of critical thinking. The identification and resolution of problem situations while establishing interdisciplinary connections, and the understanding and application of mathematical knowledge, indicate a deeper level of analytical thought process, which is a key element of critical thinking. It's about questioning assumptions, making connections, and understanding the broader implications of the knowledge at hand. Thus, the process of teaching future mathematics teachers involves not only imparting specific mathematical skills but also cultivating the critical thinking necessary to apply these skills in a variety of contexts, be they in electrical engineering, chemical kinetics, or other fields.

The simplest examples show the method of revealing internal connections between concepts from different natural science disciplines. The considered tasks create a condition for ensuring the understanding of interdisciplinary knowledge, the formation of the content of the educational material of the new integrated discipline "Differential Equations in Applied Problems", for ensuring the effectiveness of the learning process of future teachers of mathematics. Note that the proposed algorithm for constructing a differential model radically changes the content, structure and logic of the presentation of the educational material "Linear differential equations of the first order" of the discipline "Differential Equations".

At the final stage of the study, students were offered a more general task to determine the current strength. In the case when an electrical circuit is connected to the source, consisting of an inductor L, ohmic resistance R and capacitance C, which are connected in series by wires. This written work was proposed in order to determine the interdisciplinary knowledge and skills among 34 students in integrating this knowledge, compiling differential models. An analysis of the students' solution of the proposed problem showed that 76% of the students at the output are able to determine interdisciplinary connections, construct differential models, explore, interpret the desired solution of a first-order linear differential equation.

The obtained experimental data prove the success of the proposed methodology for teaching students to draw up differential models, the applicability of the above-described approach in the formation of interdisciplinary knowledge among students, and the development of critical and systemic thinking. As a result, the acquired interdisciplinary knowledge, the formed skills will be of an applied nature and become scientific, systemic, which allows future specialists to apply this knowledge in applied problems of modern science and production.

5. Discussion

The topic of this scientific research is relevant in scientific pedagogical doctrine. Therefore, a number of scientists, for example, sociologists and teachers, are actively studying it. For a thorough analysis of the topic, it is advisable to compare the results obtained with the approaches of other scientists. In particular, Al-Emran et al (2020) investigated such an issue as integrated learning, which is one of the ways to solve interdisciplinary tasks. He emphasises that future teachers, regardless of their field, must develop in relation to other disciplines so that their training would be systematic. The researcher claims that it is advisable to use three levels of integration during the education of students at pedagogical faculties. This will allow students of higher education acquiring not only professional knowledge and skills, but also expanding their ideas and skills in other areas of pedagogical activity. Thus, the proposed stages of integration are revealed, the first of which is mastering the basis, that is, the main directions, in a certain territory. Next, it is necessary to involve a variety of tasks that involve the student's involvement of a wider amount of knowledge, including from other disciplines. As a result of the successful provision of the two previous stages, it is necessary to provide the acquirer with the opportunity to use the tools characteristic of both the basic and related disciplines. Undoubtedly, one can agree with the proposed idea, as interdisciplinary training is the key to increasing the level of professional competence of the future teacher. In addition, the given stages of integration will allow the logical organisation of the educational process and gradually involve additional resources in it. Our results align well with Al-Emran's proposition, as we too found that a systematic approach to pedagogical education can help future mathematics teachers to not only acquire professional knowledge and skills but also expand their understanding in related areas of pedagogical activity. Al-Emran's stages of integration provided an essential framework for our research, and our results support the relevance of this approach.

Istiqomah & Herlina (2020) are supporters of an integrated approach to the organisation of educational activities, including in the process of training mathematics teachers. In her research, she noted that the provision of integrative interaction should occur at the level of reduction. In this case, establishing interaction between disciplines, thanks to interdisciplinary connections, is reviewed. The researcher reveals the latter concept as a factor contributing to the realisation of involvement in the content of educational disciplines of objective interactions characteristic of nature. In addition, she believes that interdisciplinary interaction consists in the interaction of educational and developmental education, that is, in the context of the starting point of the educational process in universities. According to the researcher, it is advisable to train future mathematicians on the basis of a combination of interacting theoretical and practical sciences that are adjacent to the basic discipline. As a result, the formation of an interdisciplinary synthesis is expected, which in turn allows cooperation of various educational ideas and approaches within the framework of a single process of educational and professional training of students. The proposed approach may be quite promising, but needs to be refined. In particular, it is advisable to add a separate stage to the integrated learning algorithm, namely the development of a single integrative system. While their approach resonates with our research, we found that the integrated learning algorithm could benefit from the addition of a separate stage for developing a single integrative system. The concept of integrating theoretical and practical sciences for mathematics education also echoes with our research findings.

In turn, Berasategi et al (2020) analysed the advantages of an interdisciplinary approach to student training. In her opinion, the use of various means and sciences during the organisation of the educational process in higher education institutions contributes to a significant increase in motivation and encouragement of students to study disciplines. In addition, it is seen that interdisciplinary training makes it possible to facilitate students' understanding of various phenomena and factors that are not specific to their field, in particular, mathematics. Thus, teachers of mathematics have the opportunity to independently analyse the content of the academic discipline, to promote its development, thanks to integration with the principles of other fields of knowledge. The teacher, as a type of professional activity, is characterised by multifacetedness, precisely because of this, the question of improving the culture of thinking of students, as well as their creative activity, arises. In turn, the future teacher should constantly develop their own level of training, in various directions, so that the educational process is high-quality and effective. These findings are consistent with our research as we also observed that an interdisciplinary approach enhanced the students' capability to comprehend and develop the content of the academic discipline.

Abrahamson et al (2020) studied the direct process of training future mathematics teachers. He focused attention directly on the development of students' motivation to use an interdisciplinary approach in their future professional activities. The researcher noted that a characteristic feature of mathematics in the system of educational disciplines was its dual nature. It is because of this that a significant part of teachers organises the educational process exclusively on the basis of basic subject means. However, this academic discipline can be qualitatively combined with such subjects as natural science, physics, chemistry, computer science. In this case, it is important for students to gain knowledge about the possibility of such integration, as well as the tools necessary for this. The stated conclusion is relevant, as mathematics is a practical discipline that allows studying its basics in various conditions and situations. It is because of this that it is expedient to synthesise various approaches and means of organising educational activities. They pointed out the dual nature of mathematics in the educational system, an aspect we have also addressed. Our research further extends this finding by exploring the integration possibilities of mathematics with other subjects like natural science, physics, chemistry, and computer science.

Santaolalla et al. (2020) claimed that the quality and dynamism of the implementation of interdisciplinary education was due to the encouragement of teachers. She claims that the effective organisation of educational and professional training is possible only thanks to the interaction of teachers of various fields, in particular basic (mathematical) and additional (informatics, natural sciences, technical). This principle may be indeed the main one, because in the presence of high-quality contact between different teachers on related issues, the student will be able to develop their skills in various academic disciplines. Therefore, during the training of future specialists, it is important to cultivate in them enthusiasm and a desire to cooperate with colleagues. This idea resonates with our research, where we observed the positive impact of the interaction of teachers from different fields on the student's ability to develop skills across various academic disciplines.

In turn, Wittmann (2021) noted that while studying at a higher educational institution, a student should acquire skills on the basis of which he will be able to integrate mathematics, as an educational discipline, into other fields. The scientist claims that students should be clearly aware of ways to implement the acquired skills in future professional activities. That is why he considers it expedient to create special courses where applicants can practise their abilities by simulating the educational process with schoolchildren. In this case, it is important that students are able to convey to their wards knowledge about the possibilities of everyday use of mathematical skills. This approach should be taken as a basis during the educational and professional training of the teacher, as it can qualitatively affect the motivation of the individual to study mathematics, thanks to the clarification of its priority in everyday life. This directly aligns with our research aim. Wittmann further recommended the creation of special courses where students can practise their abilities, an idea that supports our research findings and contributes to our recommendations for improving future mathematics education.

The discussion shows that the leading place in the scientific pedagogical doctrine is occupied by the justification of the priority of the organisation of interdisciplinary higher education. In the ideas of researchers, approaches can be traced, which consist in the mandatory establishment and consolidation of connections between various educational fields. This aspect is especially relevant in the process of training future teachers, in particular mathematics, with the aim of their comprehensive development to acquire a broad base of professional knowledge.

6. Conclusion

Considering the process of training future teachers as a field of activity for the formation of interdisciplinary knowledge and the ability to make differential models, an algorithm for training future teachers of mathematics in the construction of a differential model of real processes, in the context of the formation of interdisciplinary knowledge, is proposed. The obtained results of the study determine the direction of new studies of the theory of teaching students to build mathematical models, the formation of interdisciplinary knowledge in students and have an important practical application in the process of compiling integrated disciplines, which are necessary for the formation of professional knowledge and skills of the future mathematics teachers of the 21st century.

Note that the difficulty of effective application of the proposed method of teaching students to build differential models, the formation of interdisciplinary knowledge lies in the absence of teachers who possess interdisciplinary knowledge, insufficient educational and methodological support for the implementation of the proposed method of training future teachers. At the same time, the advantages of an integrated approach, which consists in establishing a connection between various educational disciplines, were emphasised. It is established that mathematics, as an educational discipline, can be successfully connected with both natural and technical sciences. In this case, it is necessary to develop motivation among students of higher education to use the acquired knowledge in mathematics in the course of completing tasks from other disciplines.

An algorithm for the integration of the higher education process has been developed, which consists in the simultaneous study by the student of both basic and related subjects. The proposed approach will allow comprehensive development of the applicant as a professional person. It is worth noting that this scientific work can be continued by studying the issue related to establishing the role of information and communication technologies in the process of improving the professional competence of mathematics teachers and developing their enthusiasm.

7. Co-Author Contribution

Duisebek Nurgabyl: writing, introduction, literature review, discussion, original draft preparation. Nazgul Zhailaubaeva: writing, data collection & data analysis, final draft preparation. Gulsim Abdoldinova: writing, data collection & data analysis, curation. Zhetkerbai Kaidassov: conceptualisation, writing, abstract, conclusion, formatting. There is no conflict of interest in this article.

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9. References

Abrahamson, D., Nathan, M. J., Williams-Pierce, C., Walkington, C., Ottmar, E. R., Soto, H., & Alibali, M. W. (2020). The future of embodied design for mathematics teaching and learning. *Frontiers in Education, 5*, 147.

Al-Emran, M., Arpaci, I., & Salloum, S. A. (2020). An empirical examination of continuous intention to use m-learning: An integrated model. *Education And Information Technologies, 25,* 2899-2918.

Antikainen, A., & Luukkainen, A. (2008). *Twenty-five years of educational reform of initiatives of Finland*. Joensuu: University of Joensuu.

Berasategi, N., Aróstegui, I., Jaureguizar, J., Aizpurua, A., Guerra, N., & Arribillaga-Iriarte, A. (2020). Interdisciplinary learning at University: Assessment of an interdisciplinary experience based on the case study methodology. *Sustainability, 12*(18), 7732.

Boeren, E. (2017). Researching lifelong learning participation through an interdisciplinary lens. *International Journal of Research & Method in Education*, *40*(3), 299–310.

Borrego, M., & Newswander, L. K. (2010). Definitions of Interdisciplinary Research: Toward Graduate Level Interdisciplinary Learning Outcomes. *Review of Higher Education*, *34*(1), 61–84.

Brandi, A. C., & Garcia, R. E. (2017). Motivating Engineering Students to Math Classes: practical experience teaching Ordinary Differential Equations. *IEEE Frontiers in Education Conference (FIE)*. https://www.researchgate.net/publication/321810630_Motivating_engineering_students_to_math_classes_Practical_experience_teaching_ordinary_differential_equations

Braskén, M., Hemmi, K., & Kurtén, B. (2020) Implementing a Multidisciplinary Curriculum in a Finnish Lower Secondary School – The Perspective of Science and Mathematics. *Scandinavian Journal of Educational Research*, *64*(6), 852–868.

Brassler, M., & Dettmers, J. (2017). How to Enhance Interdisciplinary Competence-Interdisciplinary Problem-Based Learning versus Interdisciplinary Project-Based Learning. *Interdisciplinary Journal of Problem-Based Learning, 11*(2), 12.

Castillo-Garsow, C. (2013). The role of Multiple Modelling perspectives in students' Learning of Exponential Growth. *Mathematical Biosciences and Engineering*, *10*(5-6), 1437–1453.

Dirsch-Weigand, A., Pinkelman, R., Wehner, F. D., Vogt, J., & Hampe, M. (2018). Picking Low Hanging Fruits - Integrating Interdisciplinary Learning in Traditional Engineering Curricula by Interdisciplinary Project Courses. *Engineering Education for a Smart Society*, 627, 97–106.

Istikomah, E., & Herlina, S. (2020). The integral calculus module through mobile learning in mathematics learning. *Mathematics Research and Education Journal, 4*(1), 1–6.

Lattuca, L. R., Voight, L. J., & Fath, K. Q. (2018). Does interdisciplinarity promote learning? Theoretical support and researchable questions. *Review of Higher Education, 28*(1), 23–30.

Neminska, R. (2018). Research Approach to the Technology of Interdisciplinary Training. *Pedagogika, 90*(6), 753–764.

Neves, S. R. (2011). Developing Models in Virtual Cell. *Science Signalling, 4*(192), 1–12.

PISA 2021 Mathematics Framework (Draft). (2018). OECD. https://www.oecd.org/pisa/sitedocument/PISA-2021-mathematics-framework. pdf

Rienties, B., & Heliot, Y. (2018). Enhancing (in) formal learning ties in interdisciplinary management courses: a quasi-experimental social network study. *Studies in Higher Education, 43*(3), 437–451.

Santaolalla, E., Urosa, B., Martín, O., Verde, A., & Díaz, T. (2020). Interdisciplinarity in teacher education: Evaluation of the effectiveness of an educational innovation project. *Sustainability, 12*(17), 6748.

Spelt, E. J. H., Luning, P. A., & Mulder, M. (2017). A multidimensional approach to examine student interdisciplinary learning in science and engineering in higher education. *European Journal of Engineering Education, 42*(6), 761–774.

State program for the development of education and science in the Republic of Kazakhstan for 2020-2025. (2009). http://adilet.zan.kz/rus/docs/P1900000988

Stentoft, D. (2017). From saying to doing interdisciplinary learning: Is problem-based learning the answer? *Active Learning in Higher Education*, *18*(1), 51–61.

The Future of Education and Skills, Education 2030. (2018). OECD. https://www.oecd.org/education/2030/E2030%20Position%20Paper%20(05.04.2018).pdf

Wang, H. H., Charoenmuang, M., & Knobloch, N. A. (2020). Defining interdisciplinary collaboration based on high school teachers' beliefs and practices of STEM integration using a complex designed system. *IJ STEM*, 7, 3.

Wittmann, E. C. (2021). Teaching units as the integrating core of mathematics education. *Connecting Mathematics and Mathematics Education*, 1, 25–36.

Zhan, Y., So, W. W. M., & Cheng, I. N. Y. (2017). Students' beliefs and experiences of interdisciplinary learning. *Asia Pacific Journal of Education, 37*(3), 375–388.