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Critical thinking and hypothetic-deductive scheme for studying the elements of quantum theory

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ABSTRACT

The study provided research and experimental verification of the hypothetic-deductive scheme for teaching the theory of quantum physics to secondary school students. The study highlighted the technologies and didactic tools, which help to boost the effectiveness of teaching physics to students and develop their critical thinking. It was found that the hypothetic-deductive scheme is based on the concept of critical rationalism and it has such stages: problem-hypotheses-rational criticism-choice of hypothesis-rational criticism of the new theory-new problem. The study described the stages of its implementation for teaching students the basics of quantum physics. To prove the effectiveness of the suggested scheme, the study carried out a comparative experiment in which 479 students took part (there were 241 students in experimental classes and 238 students in control classes). The statistical procession and interpretation of the experiment results were carried out with Pearson's Chi-squared test. After the experiment, the quality of learning achievements that corresponds to the sufficient and high levels is 62.87% in the experimental classes, whereas in the control classes this figure is 52.48%. In further prospect, researchers plan to check the effectiveness of the suggested scheme to study other theories, which are studied in secondary school.

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1. INTRODUCTION

The open modern life is characterized by rapid development of information-communication technologies (ICT), by the variety of ways used to process and transfer information, by transformations in social and economic spheres, and by the necessity to adapt quickly to all these changes. Under these conditions, competencies in mathematics, physics, engineering, technologies [1], [2] alongside with critical thinking [3], [4] are considered to be the key ones in the 21st century. Knowledge of physics and mathematics is used in economics, agriculture [5], industry and many other fields. Being important, they are mandatory to learn in educational institutions of different levels. Unfortunately, these days we observe a stable trend in Ukraine when the quality of students' training in physics and mathematics is deteriorating, thus causing much concern. The results of the annual external independent evaluation (EIE) prove the previous statement and demonstrate that the number of students who cannot get even minimum points required to enter the higher educational institution is constantly increasing [6].

Various technologies and didactic tools are used to boost the effectiveness of studying physics. Quite an effective means is considered to be ICT, especially software-pedagogical tools. They are used both to develop critical thinking and to ensure the process of studying physics. In the previous work [7], there is the analysis of the software which was used while teaching physics in recent years (from 2010 to 2019). The use of multimedia physics practicum is also promising [8]. The advantages of using ICT at the lessons of physics are: a possibility to simulate physical phenomena and processes without the proper equipment, learning physical concepts, and understanding physical phenomena. The prospect trend in teaching physics is considered the use of science, technology, engineering, and mathematics or STEM-education which provides deepened learning of natural sciences and mathematics, introduction of various technologies in education [9], preparation for the real life in the conditions when different technologies are being developed and demand for specialists in STEM-professions is being increased. The effectiveness of STEM-education was proved while studying mathematics and physics [9], classical mechanics [10], nuclear physics [11], thermodynamics [12], and other subjects.

Despite the variety of tools and technologies which are used to study physical phenomena and processes, it is not always possible to obtain positive results while studying physics. While studying the basics of the quantum theory students face certain difficulties, including the lack of possibility to carry out most experiments. Also, there is a more fundamental problem-the lack of visual aids. In order to solve these problems, it is necessary to change the scheme of the learning activity, to introduce new learning algorithms according to the subject specifics, styles of teaching, and students' learning abilities. For instance, the work studied different styles of teaching and their influence on choosing the learning strategy [13]; the work provided recommendations for teachers of physics according to the chosen teaching strategy.

In those cases when there are no visual aids or when it is impossible to see or feel certain physical processes, one should consider students' thinking abilities and encourage their non-standard thinking [4]. Here, critical thinking takes the first place and it is considered the condition for the successful mastering of the learning material in physics [14], it is characterized by its complex nature and absence of algorithm [1], it favors intellectual and personal development. The structure of critical thinking includes a number of skills and personal abilities, such as an ability to assess the suggested proofs and reasons, to determine incorrectness of arguments, a desire to look for proofs while solving problems [3], to make decisions based on the analyzed proofs (evidences) and opinions [15], to process data and formulate new hypotheses [16].

It is impossible to develop the skills of critical thinking through the procession of the learning content [4] and mechanical memorizing. As a result, not all the students who are used to memorizing the text and reproducing it to a teacher are capable of abstract thinking and understanding fundamental conceptual principles [17]. For this, students need active thinking processes which make them demonstrate their mental activity and use methods of scientific cognition. The most effective methodologies for critical thinking development are analysis and generalization of resources, written and verbal argumentation and reflection, thematic research [18], discovery learning [3], and blended learning [19]. To develop the skills of critical thinking we can use such means as practical tasks on professional subjects, written creative works as a way to combine creativity and critical thinking [20], online courses on critical thinking development [21], communication, and discussion of issues with Facebook and Google Classroom [4].

The purpose of the research is an attempt to practically implement the philosophical concept of critical rationalism as a means of developing critical thinking in high school students using the example of studying quantum theory. Taking into consideration the importance of critical thinking for the development of students' personality, as well as difficulty of learning certain physical concepts, we suggested using the hypothetic-deductive scheme for studying the basics of quantum physics. In our opinion, the latter will allow us to shift accents from forming complex scientific concepts of quantum physics to developing students' critical thinking. Instead of raising the scientific level of presentation by attracting new high-tech concepts, it is necessary to form students' ability to think critically and rely on the learning material that is not overloaded with complex terminology and mathematical apparatus.

2. THE COMPREHENSIVE THEORETICAL BASIS

2.1. Rationalism and empiricism in teaching physics

The concept of critical thinking is based on the philosophy of Popper's critical rationalism (Karl Raimund Popper, 1902–1994). It is well known that classical rationalism is associated with the deductive method of cognition, when knowledge about the world can be obtained only with the "pure mind", its undoubted "innate" ideas and strictly logical reasoning that are not based on experience. It means forwarding bold theories and a constant lack of trust in them [22]. The rejection of empirical data was justified by the fact that the undoubted "innate" ideas of the pure mind are the most general truths from which less general truths can be derived by deduction. At the same time, classical empiricism declared that consciousness does not have anything that was not previously perceived. Empirical knowledge is gained through the accumulation of facts, observations and measurements that are summarized by induction.

In modern understanding, rationalism is a belief or trust in intelligence as a tool that should be based upon while studying nature. In this regard, cognition through the study of empirical laws seems more appropriate. According to the ideas of empiricism (positivism), a recommendation of recurrence in the presentation of learning material prevailed in the theory and methods of teaching physics. Hence, the process of forming new knowledge begins and ends with: Experimental facts-model-theoretical generalization-experimental verification of theoretical conclusions. The structural and logical scheme of the learning material presentation is consistent with the scheme of the learning process within the positivist concept and guarantees students' mastering the elements of physical theories. In the context of analytical philosophy, this logic of presenting educational information on the structure of matter corresponds to the general theory of cognition generated in the tradition of positivism and it fully justifies itself in school practice.

However, the empirically inductive scheme has some significant drawbacks that are particularly severe during the study of quantum physics. The main problem is the impossibility of relying on empirical experience when it is necessary to form scientific concepts that are difficult to fit in an adequate system of physical experiments and compare with students' empirical experience. It is impossible to solve the outlined problem in the framework of traditional methodological approaches, as they are based on the positivist concept of cognition. However, modern researches, related to the field theory, as well as to the study of elementary particles within the standard model, and with the help of high energies physics, made scientists gradually use new methodological tools that can solve the outlined problem if it is used in the adequate form in the educational process. In order to show how it is possible, we would like to consider the concept of critical rationalism which is an alternative to positivism and neopositivism approaches.

2.2. Critical rationalism in teaching physics

As it has been explained, the crucial stage of the cognitive process is an inductive procedure which is reflected in an adequate form in the structure of students' educational activity: Experiment-inductive generalization-theoretical generalization-theory-theory verification. Induction (logical or psychological) is unnecessary for cognition. That is why, inductive generalization needs to be removed from the scheme and change it for hypothetic-deductive tools. As a result, the new scheme will be: Problem-hypotheses-rational criticism-choice of hypothesis-rational criticism of the new theory-new problem.

Considering the hypothetic-deductive scheme, the teaching style presupposes a shift in learning goals from mastering complex scientific concepts to forming students' new type of thinking that involves knowledge of the concepts that are relevant not only in the context of recent scientific advances, but also in life outside school. Firstly, this will allow to form the semantic component of the subject under study successfully. Secondly, it will help to develop students' ability to think critically, "think like scientists" and solve educational challenges and tasks, problematic situations that occur in the life of an average student [23]. Thirdly, the extensive increase of the scientific level of presenting physical knowledge is caused by the empirically inductive approach, based on the inductive process of empirical facts accumulation, and their confirmation through a physical experiment. All this leads to the inevitable increase in the volume of the learning material that students must study.

The central idea of Popper's epistemological concept is the idea of rationalism. Within the concept of critical rationalism, rationality, in fact, has a different semantic content-instead of having to prove validity or high probability of the theory validity (hypothesis) and act as a guarantor of this validity, one has to choose the theory that best meets certain criteria (laws) and withstands rational criticism compared to alternative theories or hypotheses. Rational criticism is possible in various forms-through the search for empirical facts or revelation of internal logical contradictions between this theory and alternative theories. After the theory has withstood rational criticism, it is temporarily accepted as veritable. So, the task appears: among alternative hypotheses it is necessary to choose one that best stands up to rational criticism. Popper believed that in such a way the development of scientific knowledge is carried out-by trial and error, their critical rethinking [24].

3. RESEARCH METHOD

The purpose of the study was to confirm the effectiveness of the hypothetic-deductive scheme for studying quantum physics. Lyceum students who studied the section of quantum physics for 10 academic hours with the application of the proposed scheme took part in the research. The students were divided into two groups, which were approximately the same by the number of respondents: control classes (CC) and experimental classes (EC). The experimental group studied quantum physics using the hypothetic-deductive scheme, and the control group studied it according to the traditional method.

When determining the degree of physical knowledge possession, we focused on four levels of students' learning achievements (low, medium, sufficient, and high), which correspond to the levels adopted in schools of Ukraine. To determine the levels of students' learning achievements, we checked the knowledge of actual material and the ability to apply it to solving standard physical problems. For this purpose, we developed an array of test papers on the topic of quantum physics, which we offered to students during the control assessment after studying the relevant topics.

The obtained empirical data on the learning achievements of CC and EC students were processed with Pearson's Chi-squared test in the following sequence:

a) Hypotheses were put forward: i) The difference in the grades which students receive for the test work in the experimental and control classes is caused by random factors (H_0). In fact, the level of knowledge, skills and abilities of students in both groups is generally the same; and ii) The difference in the grades which students receive for the test work in the experimental and control classes is explained by the use of a new hypothetic-deductive scheme for studying quantum theory and by the development of students' ability to think critically (H_1).

b) The critical area $\chi^2$was found by the (1):

$$\chi^2 = \sum_{i=1}^{C} \frac{(f_0 - f_e)^2}{f_e} \tag{1}$$

To find the critical value of χ^2_{cr}, the number of degrees of freedom was found as in (2):

$$q = C - 1 \tag{2}$$

Where, C is number of categories (in our case C=4). So according to (1), $q = 4 - 1 = 3$. The area of χ^2 was found by the table of Chi-square distribution as shown in Table 1.

c) Statistics of Chi-square was calculated. At first, we calculated the expected frequency according to H_0, then we calculated the value of χ^2 criterion

d) Comparing the critical value χ^2_{cr} with the empirical χ^2, we rejected one of the hypotheses and confirmed the other one.

e) If H_1 was approved and H_0 was rejected, then we analyzed the quantitative indicators demonstrating the distribution of students in the control and experimental classes by the levels of learning achievements based on the knowledge assessment. Considering this analysis, we could draw a conclusion about the effectiveness of the suggested hypothetic-deductive scheme for studying quantum physics in secondary school.

Table 1. Distribution of Chi-square

q	Level of significance α				
	0.10	0.05	0.025	0.01	0.005
1	2.71	3.84	5.02	6.63	7.88
2	4.61	5.99	7.38	9.21	10.06
3	6.25	7.81	9.35	11.34	12.84

4. RESULTS AND DISCUSSION

4.1. Stages of implementation of the hypothetic-deductive scheme

4.1.1. Formulation of the educational problem

The formulation of the educational problem implies the existence of a contradiction between the knowledge acquired by students and the new educational material that they need to learn. In our opinion, in a methodological sense, it is more appropriate if such a contradiction is revealed on the basis of physical theory. That is studied at an adequate level in secondary school. For example, such a contradiction can be found in the historical retrospective of the quantum theory formation.

4.1.2. Putting forward a hypothesis that is aimed at solving the problem

The study conventionally divided the methodology of teaching students to put forward a hypothesis into two stages. The first stage-the teacher using new educational material shows the course of reasoning for formulating a hypothesis. At the second stage, during the presentation of new educational material, the students do the same under the teacher's guidance. Eventually, when they acquire stable skills of hypothesis-making, they will be prepared to put forward hypotheses independently.

The teacher begins the lesson with a structured review-a short message to prepare students for the new topic and to increase their interest. Next, he/she demonstrates the phenomenon of the photo effect with the help of a physical experiment: a carefully cleaned zinc plate, which is negatively charged, is attached to the electrometer. If the plate is illuminated by an electric arc or a mercury-quartz lamp, the needle of the electrometer falls down. The teacher asks students to answer several questions: i) What does the movement of the electrometer needle indicate?; ii) Did the plate have an excess or deficiency of electrons before being illuminated?; and iii) What can be said about the number of electrons on the plate after it was illuminated?

The students should discuss their assumptions among themselves and express their thoughts about what they saw. After the discussion, they come to the conclusion that the movement of the electrometer needle indicates that it is rapidly discharging; since the plate was initially negatively charged, so the excess electrons on the plate decreased. After that, the teacher asks the students to make an assumption that will explain why the electrometer discharges when it is illuminated with light, or where did the excess electrons go when the plate was illuminated?

In order to formulate a hypothesis, the teacher explains students that they have to make a hypothesis by taking several steps. First of all, they have to define variables. Variables can be dependent and independent. Independent variables are those ones that can be chosen during the experiment, they are chosen at their own discretion. Dependent variables are those ones that can change and depend on the chosen independent variable. The dependent variable varies according to the law of physics under study. For example, in the discussed experiment, the plate discharge is a dependent variable. It can have two meanings-“the plate is discharging” or “the plate is not discharging”. For example, you can choose an independent variable (to change the frequency of light or change the charge of the plate) and see what happens to the dependent variable-the discharge of the plate.

The next step is the formulation of a hypothesis. The teacher draws the students’ attention to the fact that the hypothesis should be in the form of a statement, which refers to a prediction regarding the relationship between the independent and dependent variables. To help the students, the teacher offers to follow the well-known forms: “If ..., then ...” or “Supposing ..., then ...”. For example: “If the independent variable have the meaning A, then the dependent variable will have the meaning B.” An important (mandatory) parameter of the hypothesis is the possibility of its experimental verification.

If we take into account, we can formulate the following assumption: If the light of a certain frequency “tears” electrons off the surface of the plate, then the electrometer discharges. So, the formulated assumption explains the experiment observed by the students. However, it should be subjected to a critical analysis to ensure that it adequately explains the relationship between the variables.

4.1.3. Rational evaluation and critical analysis of the hypothesis

Now the previously formulated assumption, which reflects the reduction of the plate charge when it is illuminated by light, should be subjected to a critical analysis. Rational evaluation and criticism of a hypothesis is an important stage in the formation of critical thinking skills, since it is during the testing of a hypothesis that the “mechanisms” of critical thinking are turned on. Testing and critical analysis of the hypothesis takes place in three stages: i) Choosing a method of measuring variables; ii) Application of isolation and control principles; and iii) A conclusion about the existence (or absence) of a causal relationship between variables (correlation and causal relationship).

In the experiment with the zinc plate, the variables are the plate charge and its illumination. According to the first point, we chose the method of defining the variables. The teacher explained that the charge on the plate can be estimated with the help of an electrometer, since it is not necessary to know its value exactly, but only the fact of changing the value of the charge.

The students, with the help of the teacher, put forward and checked a new hypothesis: if the plate is charged with a positive charge (independent variable) and illuminated in the same way, then the plate will not discharge (dependent variable). To test the chosen hypothesis, the teacher repeated a demonstration experiment with a positively charged plate, which confirmed the hypothesis. The last step is the conclusion about the existence of a causal relationship. In this case, such a connection exists between the illumination of the plate and the ejection of electrons (discharge of the plate).

4.1.4. Formulation of provisions (postulates) of the new theory

Similarly, putting forward hypotheses regarding the explanation of the photo effect, we explain its mechanism. Based on the confirmation of these hypotheses, the main provisions of the photo effect theory are formulated. At the same time, special attention is paid to the principle of isolation-in order to establish a functional relationship between two variables, other variables must be fixed.

4.1.5. Rational criticism of a new theory

Theory criticism is similar to the stage of the rational criticism of the hypothesis. This important stage should help students understand that the acceptance of a hypothesis does not mean its final truth, which is no longer subject to doubt. On the contrary, scientists are always ready to change a hypothesis or an improved theory under the influence of new facts. Therefore, by criticizing the theory, there appears an opportunity to show the limits of its application.

4.1.6. Clarification of scientific problems of the new theory, possible options for their elimination

After the main points of the theory have been clarified, it is worth asking the students to find out the answers to those questions that the theory cannot explain. For example, can the photon theory of light explain the phenomena of dispersion, interference, and diffraction? Conversely, you may try to explain the phenomenon of the photo effect on the basis of the wave theory. In the methodological context, the last point of the considered scheme of studying physical theory makes it possible to logically move on to the study of the following topics of the quantum theory, in particular when studying the structure of the atom.

4.2. Data analysis

The total sample of students who participated in the experiment was 479 (n=479). There were n_1=242 students in the CC, and there were n_2=237 students in the EC. When determining the critical area χ^2, the following was taken into account. For pedagogical research and taking into account the sample size, the level of significance was chosen at 0.05 and 0.01. So, for q=3 and α=0.05, in accordance with Table 1, we got $\chi^2_{cr} = 7.81$. For α=0.01 we have $\chi^2_{cr} = 11.34$. Thus, in our case the critical area as in (3):

$$x^2_{cr} = \begin{cases} 7.81(a \leq 0.05) \\ 11.34(a \leq 0.01) \end{cases} \tag{3}$$

At the next stage the expected frequency was determined as (4):

$$f_e = 0.25 \cdot (n_1 + n_2) = 0.25 \cdot 479 = 119.75 \tag{4}$$

The observed frequency f_0 for the corresponding level of learning achievements is equal to the sum of the number of students in the control and experimental classes for each category (the level of learning achievements), where $\sum f_0 = n$. The results of the students' performance for the test work and the calculated results according to the results of the test papers are presented in Table 2.

Table 2. Calculation of the Chi-square criterion for the empirical distribution of students in the CC and EC

	Levels of learning achievements				Total
	Low	Medium	Sufficient	High	
Number of students in the CC	50	65	69	63	242
Number of EC	39	49	75	84	237
Observed frequency f_0	89	114	144	147	479
Expected frequency f_e	119.75	119.75	119.75	119.75	479
$f_0 - f_e$	-30.75	-5.75	24.25	12.25	0
$(f_0 - f_e)^2$	945.56	33.06	588.06	150.06	
$(f_0 - f_e)^2/f_e$	7.896	0.276	4.911	1.253	14.336

According to the (1), we calculated Chi-square as (5):

$$\chi^2 = \frac{(89-119.75)^2}{119.75} + \frac{(114-119.75)^2}{119.75} + \frac{(144-119.75)^2}{119.75} + \frac{(132-119.75)^2}{119.75} = 14.336 \tag{5}$$

Comparing the obtained empirical $\chi^2 = 14.336$ with the critical area (3), we drew the following conclusion. Since $\chi^2 \geq \chi^2_{0.05} = 7{,}81$ and $\chi^2 \geq \chi^2_{0.01} = 11.34$, i.e., the empirical xi-square criterion belongs to the area of significance, we reject the H_0 hypothesis and accept the H_1 hypothesis instead. Therefore, the difference in the grades obtained for the test work by the students in the experimental and control classes is explained by the use of the suggested hypothetical-deductive scheme for studying the quantum theory.

The assessment of the dynamics in the quantitative indicators which demonstrate the distribution of students according to the previously developed levels showed that their redistribution occurs during the learning process. The quality of students' practical skills and acquired knowledge corresponding to the sufficient and high levels of learning achievements is 62.87% (31.65%+31.22%) in the experimental classes, whereas in the control classes it is 52.48% (28.51%+23.97%) as shown in Figure 1.

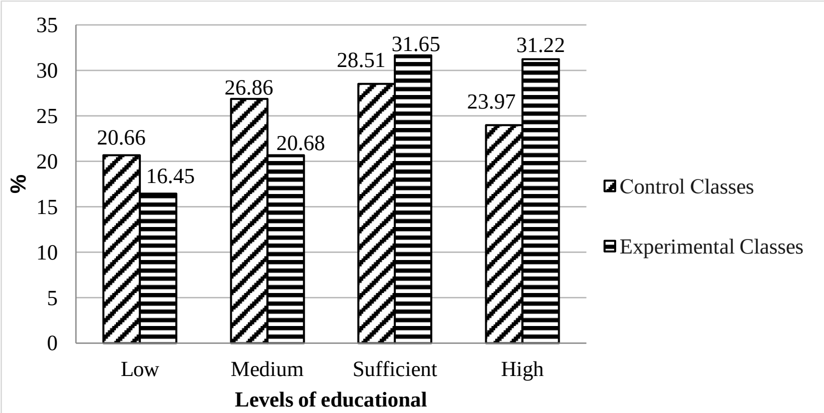

Figure 1. Distribution of students by levels of educational achievements in control and experimental classes

The obtained results confirm the effectiveness of the hypothetic-deductive scheme used for studying quantum physics by secondary school students. In our opinion, orientation of the education system at the personality of a student, introduction of a competence approach, expansion of possibilities for communication by means of the Internet have led to new educational paradigms based on creativity, variety of means for information procession [13]. Under these conditions, critical thinking skills have a great influence on people's private and social life, their professional activity [4], [18], they allow taking independent decisions based on the critical analysis of the given information and reflect personal mental activity. However, it is necessary to work hard so that to develop critical thinking, since students' notes and mechanical memorizing will not help students develop certain mental abilities [25]. Students must have a certain volume of knowledge [1], corresponding motivation [26], they must solve practical tasks of a high level [3], work independently or in a team depending on the learning task that was set.

When teaching physics, we have several techniques that can form certain learning achievements, in particular empirical-inductive and hypothetic-deductive schemes of the cognitive process. We carried out a comparative analysis of these schemes and it showed their conceptual differences. Firstly, they differ in the place and role of a physical experiment in the learning process. Secondly, the second scheme provides a procedure of the rational hypothesis (or hypotheses) criticism. Thirdly, they are different in the element that closes the cycle-for the first scheme this element is an experiment (demonstrative or frontal experiment in the educational process), and for the second scheme it is a problem situation which must be solved by means of a hypothesis (hypotheses) critical analysis). Fourthly, the given approaches are different methodologically, i.e., they are different in prevailing scientific methods of cognition-in the first scheme the initial is the inductive procedure, in the second one it is a deductive method of cognition.

The study developed the suggested hypothetic-deductive scheme in order to boost the effectiveness of teaching the basics of the quantum theory. However, hypothetically we can claim that this approach will allow teachers to boost the effectiveness of teaching other theories which are studied at the lessons of physics, mathematics, and other natural sciences (chemistry and biology). Out of doubt, it will require further research.

In our opinion, hypothetic-deductive scheme for teaching students can be used together with the elements of STEM-education and ICT. For this, we can use electronic modules, which are fully or partially deal with quantum physics and provide interactivity, visual aids, and critical thinking development. For example, you can use a module in nuclear physics [11]. At the same time, STEM-education can be considered an alternative learning strategy [10], and the electronic modules can be seen as alternative learning materials [11], which are given in an electronic form and provide the educational process with interactivity and multimedia [12]. As for communication and discussion of learning tasks with the help of social networking sites and educational platforms [4], in this case special attention is paid to the social competence as an ability to avoid or solve conflicts and respect the opponent's opinion [27].

During the work in the classroom, there is a teacher, who is a facilitator of knowledge and sometimes a friend. The research [28] proves that the cooperation between the teacher and students have a positive influence on the development of critical thinking skills and team work. Owing to the supervised teaching, students learn how to assess the given information in a critical way, check its reliability, formulate an alternative point of view to solve the task [3]. The important condition for studying physics is testing the skills of critical thinking [29], including computer testing.

It should be mentioned that for the implementation of the given tasks the teacher must be properly prepared: he/she must have a developed ability for critical thinking [30], good academic training, and democratic attitude towards students. It is recommended that teachers should be acquainted with current strategies of critical thinking development [15]. Besides, it is necessary to have lesson plans, teaching materials, adequately developed tasks (practical, creative, and situational tasks), means of identifying the level of critical thinking formation in the relevant educational subjects.

5. CONCLUSION

Thus, critical thinking as an end-to-end skill in its different interpretations and models can be presented as a pedagogical technology, which ensures competence approach in teaching physics. This technology contains aims, which reflect the knowledge component, practical skills and abilities, experience that let us use the gained knowledge and skills in everyday situations; it also includes value attitudes, which were formed in course of the educational process. In order to boost the effectiveness of teaching physics we can use different technologies and didactic tools (pedagogical tools and STEM-education). At the same time, while studying elements of the quantum theory students face difficulties which are caused not only by the lack of possibility to carry out most of experiments, but by a more fundamental problem-almost complete lack of visual aids.

In order to solve the mentioned problems which appear in course of teaching quantum physics and which are difficult to visualize, it is necessary that the empirical-inductive scheme should be changed for the hypothetic-deductive one. It covers the process of cognition in such a sequence: Problem-hypotheses-rational criticism-hypothesis choice-rational criticism of the new theory-new problem. This scheme for studying physical phenomena is based on critical thinking which structurally consists of the aims that reflect the knowledge component, practical skills and abilities, experience of using the gained skills and abilities in everyday situations, as well as value attitudes which were formed in course of the educational process.

To check the effectiveness of the proposed hypothetic-deductive scheme, we carried out a comparative experiment in which there were 242 students in the control classes and 237 students in the experimental classes. The result procession was done with Pearson's chi-squared test. While determining the critical area, the study found that the hypothesis H_0 was rejected and hypothesis H_1 was accepted (difference in the grades that students received for the test work in the experimental and control classes and according to the use of the hypothetic-deductive scheme for studying the quantum theory). The quality of practical skills and gained knowledge which correspond to the sufficient and high levels of learning achievements in the experimental classes is 62.87%, whereas in the control classes it is 52.48%. Due to the application of this scheme, students of the experimental classes acquired both knowledge and methods of applying their own knowledge and experience. In the context of teaching natural sciences, the authors find interesting and promising to carry out a more substantial verification of the effectiveness of the hypothetic-deductive scheme not only for studying the quantum theory, but other theories which are currently studied in secondary school.

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