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Critical thinking in STEM (science, technology, engineering, and mathematics)

Pensamiento crítico en CTIM (ciencia, tecnología, ingeniería y matemáticas)

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ABSTRACT

The purpose of this study is to determine the place of critical thinking in the training of future teachers. To conduct the study, a survey of 200 full-time bachelor students of the Herzen State Pedagogical University of Russia was organized. All students study in Natural Sciences. The study analyzed several integrated tasks that can be aimed at the development of critical thinking. According to the results, critical thinking plays an important role in the educational process, which must be taken into account in the training of future teachers.

Keywords: Critical Thinking in STEM, Teaching Critical Thinking, Teaching Education.

RESUMEN

El propósito de este estudio es determinar el lugar del pensamiento crítico en la formación de futuros maestros. Para llevar a cabo el estudio, se organizó una encuesta a 200 estudiantes de licenciatura a tiempo completo de la Universidad Pedagógica Estatal Herzen de Rusia. Todos los estudiantes estudian en ciencias naturales. El estudio analizó varias tareas integradas que pueden estar dirigidas al desarrollo del pensamiento crítico. Según los resultados, el pensamiento crítico juega un papel importante en el proceso educativo, que debe tenerse en cuenta en la formación de futuros docentes.

Palabras clave: Enseñanza de la Educación, Enseñanza del Pensamiento Crítico, Pensamiento Crítico en CTIM.

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1. INTRODUCTION

What is critical thinking? One of the earliest definitions is "critical thinking abilities required to analyze, process, and evaluate arguments" (Schlecht: 1989, pp. 131-140). There are "higher-order thinking" and "critical thinking". There is a difference between low-level mental activities such as "memories" or "high-level" mental activities. Therefore, we can conclude that critical thinking is high-level thinking and has the following features: analysis, evaluation, rationality, and reflection. It is self-correcting and context-sensitive, and it allows judgments about the world (Nystrom: 2000, pp. 8-33; Jeevanantham: 2005, pp. 118-129).

By encouraging critical thinking, we teach the student what we believe to be right, but we encourage the student to scrutinize the evidence and judge for himself or herself the veracity of our statements. Encouraging critical thinking means that teachers respect students' rights to certain intellectual research processes (Poce et al.: 2012, pp. 47-63). Critical thinking is a major goal in higher education and also one of the key competencies included in the European reference framework (Hoskins & Crick: 2010, pp. 121-137). It is seen as a set of skills that are needed to contribute to student success during the study and in the workplace (Partnership for Twenty-first Century Skills: 2003). That is why Universities strive to develop students' critical thinking skills.

In modern discussions about the nature of higher education, the concept that emerges most widely is the idea of critical thinking. The obvious importance of critical thinking is evident in many academic teaching practices (Chanock: 2000, pp. 95-105). In many academic assignments and abstracts intended for students, a basic intellectual task is often based on the idea of critical evaluation in some way: critically analyze X or give a critical discussion of Y (Barrie, & Prosser: 2004, pp. 243-246).

For example, chemistry as a science has a pluralistic constitution, which can be characterized by epistemological, ontological, methodological and axiological aspects. The discipline has a dual character, as it has features of Natural Sciences and technology. The goals of a chemical enterprise are inextricably linked to basic human goals and objectives. A variety of social, political, economic, environmental and ethical implications of chemical thinking and action have been analyzed in several studies on the history and philosophy of chemistry.

Critical thinking is a central element of problem-solving at all levels of science, technology, engineering, and mathematics (STEM) education (National Research Council: 2006). In both primary and advanced classes, students are encouraged to identify important spatial relationships related to scientific concepts and to predict how the transformations of these relationships affect physical and biological systems.

The application of critical thinking in the STEM curriculum has resulted in a learning environment that attempts to support and train this type of thinking in a variety of disciplinary contexts. Projects range from those that try to teach the skills of fundamental visual spaces through sustainable practice to those that create critical thinking through strategy selection. Such efforts have not yet led to significant improvements in STEM achievement or degree achievement, although several individual projects demonstrate the prospect of improved thinking in the context of spatial abilities (Behar-Horenstein, & Niu: 2011, pp. 25-42; Utemov et al.: 2018, p. 12).

Everything discussed above makes it possible to draw some conclusions:

(1) Critical thinking involves more than just the mastery and application of certain skills in logic.

(2) Critical thinking includes the ability to think critically and the propensity to apply it extensively. It includes both emotional and cognitive components.

(3) Many of the definitions of the scientific approach put forward suffer from a narrowly conceived view of the nature of scientific research and the actual behavior of scientists.

(4) Greater use of critical thinking in natural science students can be achieved by studying the Natural Sciences in the context of social, economic and applied problems in which they can learn to apply critical standards in a science-related context (Dumitru: 2012, pp. 143-147).

Thus, we can say that critical thinking plays an important role at all levels of science education. Based on this, we can highlight the objectives of this study:

- To survey students to identify possible problems associated with critical thinking in teaching science;
- To analyze possible tasks that future teachers of chemistry and physics can use to develop critical thinking in their lessons;
- To form possible ways of solving problems.

2. MATERIAL AND METHODS

2.1. Research design

Based on the goals, it was decided to conduct an empirical study, which consisted of a survey of students. The study used the methodology of quantitative research to collect and analyze the interpretations and values of the questionnaire. The survey was a questionnaire aimed at asking general questions related to critical thinking. In the second part of the study, some tasks in chemistry that require the use of critical thinking were analyzed.

2.2. Participants

The ban empirical study was organized and conducted, which consisted of a survey of 200 full-time students-bachelors of three departments of the Herzen State Pedagogical University of Russia. The number of interviewed men and women was approximately equal (46 percent of men and 54 percent of women). The age of respondents ranged from 20 to 21 years old. This was because students of this age have passed most of the curriculum. Target sampling (objective sampling) was considered to be the most appropriate sampling method. All students have trained in Natural Sciences pedagogical directions.

2.3. Research instrument

The first stage was a mini-survey consisting of eight questions. The survey was aimed at finding out whether students understand the concept of critical thinking and how they see its place in the educational process. The first question (Do you know the concept of "critical thinking"?) is the most general and is asked to find out whether students are familiar with the concept of critical thinking. Even though this definition is quite common and can be used in everyday speech, some respondents may be unfamiliar with it.

The purpose of the second question (Do you use critical thinking in the classroom?) is to find out whether students believe that they apply critical thinking in the learning process.

The analysis of the received information helps people to learn better, as it is not mindless memorization. Critical thinking plays an important role in this process, allowing you to assess the incoming material. In the next question (Do you know that critical thinking helps you to learn the material better?) it is found out whether the surveyed students understand this.

Critical thinking is an integral part of the learning process, so future teachers should be taught how to use it in the classroom. The next question (Are you taught to apply critical thinking techniques in your future lessons?) is aimed at finding out whether students believe they are being taught to do so. As it is mentioned, critical thinking helps to evaluate the incoming information, which inevitably leads to the development of the ability to analyze, as well as increases the efficiency of assimilation of the material. In the fifth question of this survey (Do you think that critical thinking helps to learn the material better and develop the ability to analyze?) students are asked to assess whether this is the case.

In the next question (Is it fair to say that the project activity develops critical thinking?) respondents have to express their opinion on the level of involvement of critical thinking in project activities. Although the

importance of this type of thinking in the project is obvious, it is important to find out whether future educators are aware of it.

The purpose of the next question (Would you like to know more about critical thinking in learning?) is to find out how students are interested in applying critical thinking in their future teaching activities. Extracurricular activities provide ample opportunities to expand the educational process. The purpose of the last question (Is it possible to develop critical thinking in extracurricular activities?) is to find out whether students consider it possible to apply and develop critical thinking on extracurricular activities.

2.4. The participant's selection criterion

The survey was conducted among third-year and fourth-year students studying in the field of Natural Sciences. The criterion of this selection is because at this stage of training students have already passed most of the curriculum and practice at school. This allows them to be more knowledgeable about the topic.

2.5. Research issues and restrictions

The study involves only students receiving higher education. All respondents also live in the city of St. Petersburg and Leningrad region, which does not indicate the problem on a larger scale. That is why several problems and difficulties, identified in the study, and recommendations for their solution can be more applicable only to this group of respondents.

2.6. Data analysis

The analysis of the survey data was carried out in the STATISTICA system. This software, developed based on Microsoft Windows, allows you to visualize data in statistical analysis. The size of the error is 2 percent, about 4 questionnaires were incorrectly filled (some respondents did not answer all questions of the questionnaire or chose more than one answer option).

3. RESULTS

The results of the first question are expected to be high – 98% of respondents have said they are familiar with the concept of critical thinking. However, there is a small percentage of those who are not familiar with this concept. Quite a large percentage (78%) has reported that, in their opinion, critical thinking is used at the University. This may indicate that students understand how this type of thinking is related to the learning process and actively use it in learning.

In the following analysis, 71% of the students agreed that critical thinking helps to learn better. This may indicate that they are aware of the mechanisms of their work and their application.

Oddly enough, only 55% of respondents have reported that they are taught to apply critical thinking in their future teaching activities. The reasons for this rather low result can be two. Firstly, students do not simply realize that they are taught this technique. Secondly, they cannot explain the use of critical thinking in the classroom.

81% of respondents have agreed that the use of critical thinking allows them to learn the material better and develop the ability to analyze. This is another confirmation that students are aware of the mechanisms of critical thinking and its importance.

As for project activities, 74% of respondents have agreed that they develop critical thinking.

This result can be considered positive, as it suggests that students understand the principle of working on projects and all aspects of learning activities that it affects.

An expected high percentage (91%) of respondents has expressed their desire to study critical thinking in learning better. This suggests that students are aware of the importance of this type of thinking in learning, as well as seek to maximize their professional competence, using modern methods.

Many respondents (68%) have agreed that extracurricular activities can be used to develop critical thinking. This may indicate that students understand the importance of additional classes and consider them a full-fledged element of the educational process.

The purpose is to study the effect of various substances on human health.
The composition of fruits and vegetables includes various chemical elements and substances. 100 g of apples contain 86 g of water, 0.8 g of starch, 278 mg of potassium, 110 mg of copper, 26 mg of sodium, 16 mg of calcium, 11 mg of phosphorus, 9 mg of magnesium, 2.2 mg of iron, 2.0 mg of iodine, 0.047 mg of manganese, 2 mg of folic acid, vitamins A, B, C, H, K, PP. Apples are considered a useful product for humans. Vitamin C is involved in redox reactions, promotes the absorption of iron. Iron is involved in the transport of oxygen and the maintenance of immunity. Potassium is responsible for regulating the water and electrolyte balance. Plants can absorb from the soil saturated with fertilizers much more nitrogen compounds than they need for development, so sometimes due to improper cultivation apples contain nitrates, up to 30-50 mg. In the human body, nitrates under the action of the enzyme nitrate reductase are reduced to nitrates, which interact with hemoglobin in the blood, which leads to the oxidation of ferrous iron in it in the trivalent. This produces methemoglobin, unable to transfer oxygen to tissues and organs, resulting in reduced physical and mental activity. For an adult, the toxic dose becomes 600 mg.
What foods (of plant or animal origin) contain large amounts of nitrates?
How can I reduce the number of nitrates in vegetables?
Why spinach and parsley grown on the same soil contain different amounts of nitrates?
What nitrogen-containing fertilizers are best used to reduce environmental risks?

Task 1. Chemistry and Ecology

In this task, students are invited to speculate what chemical elements a person receives from food and whether "useful" products are always useful. Additional questions can also be added here (What form do these elements appear in? Is it the form of any chemical compounds?). Also, students can be given tips from biology, explaining the metabolism in the body.

Thus, this task allows students to develop critical thinking, as it requires the knowledge of chemistry and ecology and the ability to draw conclusions and analyze the available and received information.

The purpose is to determine the size of the particles in the solution.
Students are encouraged in several situations (experiments): 50 ml of dilute AgNO3 solution was placed in the beaker No. 1, and 50 ml of dilute NaCl solution in the beaker No. 50. Point the laser pointer beam at the glasses with solutions. What are you looking at? (The solutions appear to be optically empty.) Drain the solutions and stir. What substance is formed? What indicates the formation of a new substance? Again enlighten the resulting solution No. 3 laser pointer. What are you looking at? (There is a trace of a light beam — the Tindal effect). Pour into beaker No. 4 is a bit of detergent for dishes or shampoo. Enlighten with a laser pointer. What are you looking at? (There is a trace of a light beam — the Tindal effect). What is the optical phenomenon associated with the Tindal effect? For particles of what size (compared to the length of the light waves of visible light) is characterized by light scattering? Give examples of the effect of Tyndall in nature (the sun's rays in the forest, the light of a lantern in the fog). Based on the obtained data, it is necessary to conclude the particle size of the substance in glasses No. 1, 2, 3 and 4.

Task 2. Chemistry and Physics

To perform the task, students should know the phenomenon of diffraction scattering from the course of physics and chemical reactions of deposition and be able to analyze the obtained information. Also, performing experiments and receiving certain reactions, students should be able to think and draw conclusions based on

them. Such tasks also develop critical thinking, as they carry the reproduction of memorized material and push to own reflections.

The purpose is to study sucrose as a source of energy in the human body.
One of the main sources of energy in the body is sucrose. It's an organic compound, a disaccharide, consisting of glucose and fructose residues. Its formula is $C_{12}H_{22}O_{11}$. The thermochemical equation for the oxidation of glucose
$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + H_2O + 2820$ Kj/mol
The human body can turn into useful work only 25 percent of the energy released during the oxidation of food. If the pancreas produces an insufficient amount of insulin, a hormone necessary for the absorption of glucose in the human blood increases its amount, and the cells suffer from its deficiency. Chronic increase in blood glucose levels leads to the development of diabetes. Students are invited to explore and describe the transformation of sucrose in the body, to answer questions:

1. What compounds are formed as a result of the conversion of sucrose in the human body? What substances are involved in these reactions? Make the equations of the corresponding reactions.
2. How much sugar should a person weighing 60 kg eat to make up for the energy cost of 210 kcal per hour walk? Will this energy be enough to lift to the 10th floor (40 meters)?
3. What foods contain large amounts of sugar? What will give a frozen person more energy for warming – a portion of sweet ice cream or a glass of hot water? Caloric content of 250 calories per 100 grams.

Task 3. Physics, Chemistry, and Biology

This task also involves critical thinking, allows students to group and reduce information, highlight the most important, analyze the situation based on the data, and draw conclusions, expand the information based on the abbreviated version. Also, students learn to analyze and compare different phenomena.

Thus, it can be concluded that critical thinking plays an important role in the educational process, which must be taken into account in the preparation of future teachers.

3.1. The popularization of the idea of critical thinking

As critical thinking has many positive aspects, leading to better assimilation of the material, forming the ability to think independently, draw conclusions, etc. it is necessary to develop the idea of its use in education. For this purpose, special lectures can be held for educational institutions that prepare future teachers and for schools.

3.2. The special training of teachers

The application of critical thinking should be introduced in the training of future professionals, which requires special training for students. For this purpose, elective courses can be organized or a separate time can be given to regular classes. This will allow students to understand the importance of this type of thinking, as well as better understand how to apply it in the learning process. Also, existing teachers can be organized with refresher courses.

3.3. Changes in the curriculum

Instilling critical thinking and ideas about its importance is best to start as early as possible. To do this, changes can be made to the curriculum or extra-curricular activities, providing more relevant tasks in different subjects.

A review of the literature has shown that there are small differences in critical thinking interventions in different areas of knowledge. As for the goals of this thinking, it can be concluded that the vast majority of articles are devoted to teaching critical thinking skills, not dispositions. While humanitarian and interdisciplinary studies show this clearly, analysis and assessment seem to be the most commonly used critical thinking skills in the STEM, social, and Biomedical Sciences (Tiruneh et al.: 2014, pp. 1-17; Pakdel, & Ashrafi: 2019).

Another conclusion is that most interventions in all areas use the immersion approach, and the infusion approach is the second most common approach. This indicates a tendency to support the encouragement of embedding critical thinking in specific subject areas as a way to help students become critical thinkers rather than teaching it as a separate subject. It becomes apparent that improving critical thinking in students is more likely when learning these skills is explicit rather than implicit (Behar-Horenstein & Niu: 2011, pp. 25-42; Nooradi: 2017, pp. 71-75).

Providing a useful framework for studying the disposition of critical thinking, there is currently no tool based on triad theory. However, one published tool that quantifies the disposition of CT is the California inventory of critical thinking (CCTDI) (Facione et al.: 1994, pp. 345-350). In developing this tool, the authors adhere to the principles of the theory of triads and note that critical thinking occurs as a result of combining abilities, sensitivity, and aptitudes.

The total score represents the sum of seven subscales. Seven subscales include the desire to know the truth, readiness for new things, ability to analyze, ability to systematize information, interest, self-confidence, and maturity (Romanish: 1999, pp. 63-72).

After receiving permission to conduct the study from our Institutional Review Board, we contacted colleagues from each geographical region in their educational institutions and invited them to participate. Copies of the CCTDI, accompanying answer sheets, and a cover letter explaining the administration procedure were then mailed. Participation was voluntary.

In addition to the requested biographical information (gender, grade, and current GPA), all responses were anonymous. We followed the same procedure with the Chinese population. Tests and completed answer sheets were returned to researchers for tabulation. All sheets were evaluated, summarized and analyzed (Zheming: 2000, pp. 1-3; Mohammadi, & Yekta: 2018, pp. 1-7).

The results showed that the estimates from the USA sample were systematically higher than those from China for the four location subscales. Two areas deserve special attention: maturity of critical thinking and self-confidence. It can be said that the personality of CT-Mature approaches problems and makes decisions knowing that some problems may not have a uniquely defined solution. Thus, problems are poorly defined and judgments are often based on standards, contexts, and evidence that exclude certainty (Facione et al.: 1995, pp. 1-25).

Another study was conducted in 2017 and was aimed at finding out how critical thinking affects students' decision-making (Kanbay, & Okanlı: 2017, pp. 313-321; Laureano et al.: 2018, pp. 4-7).

All first-year students (93 people) were invited to participate. The researchers did not choose to select a sample from the population. Thus, the sample included the whole population and included 93 students who were randomly distributed either in the educational group (n = 44) or in the control group (n = 49). The data were collected in two stages. First, preliminary tests were conducted to assess critical thinking and problem-solving skills in educational and control groups, and both groups were found to have the same critical thinking and problem-solving skills. The education team was then given twelve weeks of critical thinking training, and the same tests were repeated by an instructor known to students but not involved in the study to ensure the safety of data collection (Bowles: 2000, pp. 373-376; Soldatova, & Pogorelov: 2018, pp. 105-124).

In this study, the impact of critical thinking training on problem-solving skills was discussed for similar educational and control groups that initially had similar critical thinking and problem-solving skills. Even though there was no significant difference between the average indicators of critical thinking in the educational and control groups in the preliminary testing, their post-testing was significantly different. The evaluation of critical thinking in the educational group increased, and the evaluation of critical thinking in the control group

decreased. There was no significant difference between the average estimates of problem-solving in the control group. However, the average score for problem-solving after learning in an educational group fell (indicating greater confidence in their problem-solving skills), while the score in the control group grew. This shows that appropriate education can improve critical thinking and problem-solving skills (Fero et al.: 2010, pp. 2182-2193).

Critical thinking skills can be improved by learning them. It has been found that there is a link between critical thinking and problem-solving and that critical thinking skills improve problem-solving skills. The results of this study suggest that the curriculum should be reorganized to prioritize the use of critical thinking to include a course specifically dedicated to its skills and that methods should be explored to raise critical thinking skills in younger students to a higher level (Kaya et al.: 2017, pp. 72-77; Kalogeropoulos et al.: 2020).

4. CONCLUSIONS

Thus, it can be concluded that critical thinking plays an important role in education, as it can be applied in all areas of knowledge, as well as in everyday life. This suggests that it needs to be developed. According to the results of the survey, critical thinking plays an important role in the educational process, which must be taken into account in the training of future teachers. Future teachers are not only familiar with this concept, but also interested in learning more about it for application in their educational practice.

Some recommendations can be applied for this purpose. The first recommendation is based on the popularization of the idea of critical thinking. For this purpose, special lectures can be held for educational institutions that prepare future teachers and for schools, which will help to promote the idea of the importance of critical thinking for existing teachers. The second recommendation includes the special training of teachers. For this purpose, elective courses can be organized or a separate time can be given to regular classes. The refresher courses and courses aimed at the introduction of critical thinking in the educational process can be organized for existing teachers. Changes in the curriculum can also play a positive role, as it is better to start promoting critical thinking and ideas about its importance as early as possible. To do this, changes can be made to the curriculum, providing more relevant tasks in different subjects. Also, extra-curricular activities can be organized to meet this need.

Further research could also be undertaken among students-masters or College students in a broader context. Such studies can also be conducted among citizens of other countries. The findings and results of the study can be used as a basis for other surveys or for comparing statistical data from different years.

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