

Development of critical thinking as a means of forming STEM competencies

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Abstract. The article analyzes the scientific literature in order to determine different approaches to the interpretation of the concept of “critical thinking”, describes its components, discusses the basic concepts, functions of critical thinking in teaching. Critical thinking is presented as one of the main competencies of STEM education. The conditions for the development of critical thinking in the process of STEM-learning are determined. Methodical problems are solved, which should help students to develop STEM competences based on the development of their critical thinking.

Keywords: STEM education, STEM competencies, critical thinking, competence.

1 Introduction

Today, it is important to improve the education and training system because, since the traditional education system does not fully meet the requirements and demands of the XXI century, the low level of success in the disciplines of physical and mathematical profile, as well as the lack of ability to solve real problems, are an impetus to the formation STEM competencies of students. After all, by developing STEM competences of students, we develop creativity, critical thinking, readiness to solve complex tasks, organizational abilities, emotional intelligence, ability to negotiate, cognitive flexibility, ability to interact effectively.

One of the main components of STEM competencies is critical thinking. The problem of developing critical thinking today is popular with educators. Although the term “critical thinking” itself was born recently (in the twentieth century), the issue of emotional and rational cognition has been a concern of humanity since ancient times. Even Plato related emotions such as mental excitement, pleasure, and intellectual development. Aristotle argued that the sense of wonder awakened a person to know, and believed that the very study of theoretical truth requires strong emotions.

The founders of critical thinking technology are American scientists C. Temple, K. Meredith, J. Still, and D. Ogle, who authored the Iowa Institute for Reading Thinking and Writing program at the International Reading Association of Northern Iowa and the Hubbard and William Smith Colleges. The tendency to think critically and to set its baseline was revealed by the Everyday Reasoning test.

Today, the concept of critical thinking has a large number of interpretations in foreign and domestic science.

The idea of developing critical thinking was widely spread in America and Europe by A. Lipman, R. Paul, P. Pintrich, R. Sternberg, D. Kluster, D. Halpern and others.

The works of researchers are devoted to the study of installations for critical thinking, methods of their development and diagnostics: P. Fekayon, N. Fekayon, S. Giancarlo, R. Ennis, S. Norris, G. Solomon.

In Ukraine, the problem of the development of critical thinking was first raised by Kharkiv researcher O. Tyaglo. Today, many Ukrainian researchers are devoted to the problem of forming critical thinking (N. Kozachenko, S. Terno, O. Belkin, M. Weinstein, I. Gudzik, V. Evdokimov, N. Kirpota, O. Kocherga, N. Kravchenko, V. Kushnir, M. Krasovytsky, O. Labenko, P. Lushin, V. Mayboroda, L. Masol, M. Meerovych, T. Oliynyk, and Y. Stezhko).

The composition of critical thinking, its components, strategies and procedures of critical reflection was considered in his writings by S. Terno.

2 Critical Thinking: Theoretical Aspect

Analyzing foreign and domestic literature, we can say that scientists have different approaches to the interpretation of the concept of “critical thinking”, but to date there is no single definition of it.

The idea of developing critical thinking originated in the United States. It was first introduced into education by well-known American psychologists W. James and J. Dyui.

In particular, D. Dyui [1] interpreted critical thinking as a complex, human-related activity that engulfs one completely.

The founder of the Institute for Critical Thinking M. Lipman [2] defined critical thinking as qualified, responsible thinking, capable of producing correct judgments, because it:

- a) based on certain criteria,
- b) capable of self-improvement,
- c) takes into account the context.

According to D. Cluster [3], critical thinking consists of five points.

First, critical thinking is an independent thinking. Only when critical thinking has an individual character does it become critical.

Second, information is the starting point, not the ultimate point of critical thinking. Without the motivation created by knowledge, one cannot think critically. It is through critical thinking that cognition becomes a continuous process, thoughtful and productive, and acquires individuality.

Third, critical thinking begins with the formulation of questions and the identification of problems that need to be addressed. That is why the real cognitive process is characterized by the desire of the subject to solve problems and answer questions that arise from his own needs and interests.

Fourth, critical thinking seeks convincing reasoning. Thinking critically helps a person not only find their own solution to the problem, but also to support it with a reasonable, well-founded argument. The critical thinking person is also aware that there are other solutions to the problem and tries to prove the logic and rationality of the solution he / she has chosen. Argumentation is amplified if one takes into account the existence of possible counterarguments, which are then either refuted or recognized as acceptable.

Fifth, critical thinking is social thinking. This means that any thought is checked and polished when discussed with others.

R. Paul [4] believes that in the near future, the main thing will be not the information itself, but the person who can provide it. Consequently, the ability to process information and critical thinking skills will be the key to success in the information society. He stresses that, first, critical thinking is not simple thinking, but thinking that leads to self-improvement, and second, self-improvement comes with the skills to use standards to properly evaluate the process of thinking. Therefore, according to the author, the modern world needs constant improvement of thinking skills.

P. Pintrich [5] notes that education has traditionally focused on students' actual, procedural and conceptual knowledge that it is these types of knowledge that are valued. The author emphasizes that the focus is on awareness and responsibility for one's own knowledge and thinking. The students, P. Pintrich says, will become more advanced if their thinking about cognition increases.

Critical Thinking Researcher D. Halpern [6] defines it as the use of such methods of cognition, which have controllability, validity and purposefulness, increase the likelihood of obtaining the desired end result. These methods are used to solve problems, formulate conclusions, evaluate and make decisions, and require skills that are grounded and effective for the specific

situation and type of task. It further indicates that critical thinking is characterized by the construction of logical conclusions, the adoption of sound decisions regarding whether to reject any opinion, agree with it, or temporarily delay its consideration. Therefore, critical thinking is when you need to solve a problem, formulate conclusions, make a probabilistic assessment, or make a decision, and the person uses those skills that are reasonable and effective for the specific situation and type of the problem being solved.

R. Sternberg [7] noted that “critical thinking is the thought processes, strategies, ideas that people use to solve problems, make decisions and learn new concepts”.

Michael Kallet [8] defines critical thinking as:

- manual thinking (not automatic);
- purposeful;
- being aware of the partiality of your thinking;
- a process;
- thinking that uses a tool set.

By automatic thinking, the author understands the processes that the brain performs automatically by our will. For example, when your eyes are open, billions of information bits per second are entering your brain. Your ears are always open, but you block out noise. In an attempt to simplify things for you, your brain throws things out that it doesn't deem important or thinks it already knows. The trouble is that your brain doesn't tell you it is throwing things out; it just does it. Unbeknownst to you, it also discards, distorts, and creates information. Although this tendency can be extremely helpful in many situations — such as your drive to work — it can also be a drawback. When you have to think about something important, you want to get out of automatic mode and go into manual — that is, critical thinking.

When you are learning something for the very first time, you are very attentive; you listen carefully to determine whether you understand; you're aware that your goal is to learn something, that is, you're think purposefully. Critical thinking means that you're aware of the partiality of your thinking. Humans have emotions, biases, and prejudices that stem from our values. Although it is possible to be aware of these, it is impossible to ignore them. Your values are a part of you. You cannot be completely impartial, but you can be aware of the components of your partiality and how they influence you.

Michael Kallet, notes, that critical thinking is a process, which requires that you understand a situation, come to a conclusion about what to do, and take action on that conclusion.

Critical thinking is conducted within a framework and tool set. The framework consists of a three-step process. The tool set consists of the individual critical thinking techniques used in each step to guide your manual thinking [8].

Thus, we can conclude that under critical thinking Michael Kallet understands a purposeful method for enhancing your thoughts beyond your automatic, everyday way of thinking. It's a process that uses a framework and tool set. The benefits result from changing the way you look at issues, organizing your thoughts, and incorporating other's thoughts. It stimulates new perspectives and prevents distorted views of a situation. As a result, your problem-solving and decision-making skills are enhanced.

In general, definitions in the literature are different approaches to understanding critical thinking, more often they are lists of different characteristics that researchers consider to be more important for the implementation of critical thinking. On this basis, N. Kozachenko [9] identifies the following three approaches to the understanding of critical thinking, as it is conventionally called: psychological, pedagogical, logical, methodological and scientific.

We agree with S. Goncharenko [10], who is of the opinion that the functions of critical thinking are diverse. In particular, the learning process mainly implements the following functions: awareness (conceptual function), problem-solving function (autonomy), goal-setting function and reflective function.

The most essential feature of critical thinking is a high level of awareness of one's own mental actions, and close attention to them. Mindfulness enables the realization of other properties of critical thinking that rely on and flow from it. F. Mikhailov [11] argued: "Awareness is always a movement and search for new problems, going beyond the existing ideas. Therefore, to recognize the need means to realize the problem, to understand the contradiction underlying the problem, to see the need for its solution, to look for a way to change the circumstances that will resolve the contradiction. And that means seeing the future in a new way, formulating the purpose of your actions".

Independence of thinking, as noted by S. Maksimenko [12], is based on the knowledge and experience of other people, but involves a creative approach to the knowledge of reality, finding new, own ways and ways to solve cognitive and other problems. It is a personality trait that manifests

itself in the ability to acquire new knowledge, master new methods of cognitive and practical activity, as well as use them to solve on the basis of volitional efforts of any life problems. Thus, independence generates, on the one hand, reflexivity, on the other, purposefulness.

The American philosopher and educator R. Ennis [13] was one of the first to propose the concept of critical thinking (Fig. 1).

Take care of the clarity of the rationale for decisions and views	<ul style="list-style-type: none">•to look for new hypotheses, alternative sources, conclusions, explanations;•constantly provide their own information;
Be able to clearly represent not only their position, but also the position of others	<ul style="list-style-type: none">•be sure to consider the situation as a whole, not partially;•find and offer justification for the position;•clearly aware of their own beliefs;
Respect the opinion of your interlocutor	<ul style="list-style-type: none">•be able not only to listen carefully but also to "hear" others;•condescending to another person's condition.

Fig. 1. Duties of a person in accordance of the concept of critical thinking by R. Ennis

R. Ennis developed a system of attitudes or, in other words, internal motivations for critical thinking, which have the greatest impact on the “quality” of human thinking, is very popular.

The ideas of the American researcher E. Glaser, describing the intellectual skills of critical thinking, are also the basis of modern concepts. E. Glaser [14] was the first to list a certain set of skills that, in his words, are necessary for critical thinking:

- clearly identify the problem and seek relevant aspects of its solution;
- collect and organize the information needed to solve the problem;
- identify assumptions and estimates that are not substantiated;
- accurately and selectively use and perceive linguistic means;

- explain the facts and information offered;
- evaluate their own and others' evidence, identify the existence or absence of logical connections between judgments;
- despite their own convincing and legitimate conclusions or generalizations, to question them;
- to form and expand one's own belief system, based on which to make correct judgments about everyday life.

The intellectual skills described by E. Glaser [14] were supported and developed in their studies by R. Ennis, S. Norris, R. Paul, and A. Fisher. But the question of the specific list of skills that can be attributed specifically to critical thinking still remains "open", and therefore each of the researchers of this question offers its own system, as well as the interpretation of the concept of "critical thinking". For example, R. Ennis [13] identifies more than ten basic critical thinking skills, while at the same time R. Paul's concept [4] counts three times more. Let us highlight the most essential, in our opinion, the skills that occur in most modern concepts of critical thinking:

- checking and evaluating the reliability of information sources;
- the ability to highlight and the ability to subsequently process the necessary information;
- clarity of presentation of one's position, accuracy of choice of language means;
- analysis and evaluation of statements, assumptions, conclusions, arguments, hypotheses, beliefs;
- consideration of the problem from different positions and comparison of different angles and approaches;
- the ability to ask questions to obtain information with a view to clarifying or verifying it;
- the ability to make decisions and be able to make informed choices.

The application of the aforementioned skills in everyday life or during training may be subject to prior knowledge and experience. Critical thinking is, in a sense, "thinking about knowledge" that allows you to "create new knowledge using previously acquired". The concept of "knowledge" is important to use in the broad sense of the word. According to M. Mason [15], author of the book "Critical Thinking and Learning", the psychological component of critical thinking is — "... a certain amount of knowledge,

whether knowledge of basic concepts related to critical thinking, or knowledge of a particular scientific discipline to which critical thinking can be applied". R. Ennis, for his part, believes that critical thinking has a deductive nature, linked to its interdisciplinary and extra-curricular nature of origin: a student, mastering intellectual skills of critical thinking outside of specific scientific disciplines, can apply them effectively in various fields. At the same time, J. Макрек [16], in speaking of critical thinking, emphasizes his inductive character, proposing his inseparability from a specific scientific field and considering as a paramount need for critical consideration of the problem of any scientific discipline the availability of sufficiently deep knowledge of the same discipline.

3 Critical thinking as the base of STEM education

The intensity and rapidity of social change determines the relevance of the development of STEM education. Under these conditions, there is a constant need to adapt the individual to new everyday, political, economic and other conditions, which in turn, leads to the availability of the ability to solve problems, most of which cannot be predicted and simply solved. The development and emergence of an information society in the democratic direction of the country's movement determine the importance of forming STEM competences of students in the modern education system.

One of the main tasks of STEM education is the formation of STEM competencies for students. According to the draft concept of STEM-education in Ukraine [17], STEM-competencies & skills (competencies & skills) are a dynamic system of knowledge, skills and ways of thinking, values and personal qualities that determine the ability to innovate: readiness for development integration of complex tasks, critical thinking, creativity, organizational abilities, ability to work in a team, emotional intelligence, evaluation and decision-making, ability to interact effectively, ability to negotiate, cognitive flexibility.

Critical thinking is one of the components of STEM competencies. It is defined as the ability to understand the logical connections between ideas, identify, build and evaluate arguments, identify inconsistencies and errors in reasoning (including personal), solve problems systematically, determine the relevance and importance of ideas, argue their own judgments and values, involve necessary sources of data, draw conclusions, etc. [17].

The formation of a competent personality can not be imagined without the development of critical thinking. After all, as D. Dyui pointed out [1], the fundamental goal of modern education is not to provide students

with information, but to develop their critical thinking, which allows them to adequately assess new circumstances and formulate a strategy for overcoming the problems that lie in them.

Teaching students to think critically means not only asking the teacher the right questions, directing their attention in the right direction, but also teaching them to draw conclusions and find an alternative solution. According to the psychological and pedagogical literature, the development of critical thinking involves the formation of students certain abilities and abilities:

- Knowledge — the ability to repeat something significant in the form in which it was stated and heard;
- comprehension — the ability to express ideas in their own words or otherwise;
- use — the ability to see the possibility of applying a particular idea to another case;
- analysis — ability to find causes and effects and other components of complex ideas;
- synthesis — the ability to combine several ideas into one new one or to take an idea from one medium and transform it into another; the ability to make judgments about the adequacy of a particular idea or source to explain a phenomenon.

A. Tyagol and T. Voropay [18] consider four stages of formation of critical thinking:

- 1) actualization of students' knowledge in order to awaken interest in the topic and determine the purpose of studying specific educational material;
- 2) critical comprehension of new information through reading and writing;
- 3) forming one's own opinion about the material (reflection or reflection);
- 4) generalizing and evaluating the problem, identifying ways to solve it through finding out and understanding your own capabilities.

The specificity of educational technology for the development of critical thinking is also mentioned in the methodological literature. The basic principles of this technology are that: first, the rationale of the educational process must occur through scientifically proven patterns of interaction between personality and information; second, the methodologists identified in the phase of this technology, such as challenge, reflection, reflection,

require maximum flexibility from the teacher, to take into account the learning environment and the individual characteristics of the students; third, technology uses both the principles of collaboration and joint planning of training activities and their full understanding for the implementation of learning.

The methodological literature states that every form of work, any method that can be used in the technological process of developing critical thinking, should be based on the following phases:

The first phase is the challenge. In it, the subjects of the educational process accomplish the tasks of:

- updating previously acquired knowledge of the topic. The teacher in this phase should achieve a clear organization of the process of reconstruction of the previously acquired knowledge, necessary and important for understanding the new material;

- stimulation of cognitive activity. It is necessary to create, in various ways (formulating a hypothesis, organizing work in groups, etc.), an “information void” that the students themselves wish to fill;

- creating a situation of self-determination by students of the most important directions for the study of a new topic, highlighting exactly those aspects of the topic that you would like to discuss (a person thinking critically — a person who thinks independently).

The second phase is the phase of comprehension or realization of meaning. If previous phase questions such as: “What does this mean to me?”, “Why do I need it?” set the student to understand the topic, stimulate cognitive activity and independent thinking, then in the second phase provides for the realization of the student conscious already in a certain educational and cognitive activity. The following main tasks are solved: “How to properly organize your work with new information?”, “How to effectively correlate new material with already known and previously mastered?”.

The third phase is the reflection phase. Here, reflection means “embedding”, “embedding” new experiences or knowledge into the system of personal ideas about the world. In other words, the third phase is aimed at the full assimilation of the new material so that it becomes for the student “his own”, that is, completely in line with personal opinion. For this purpose it is necessary to: a) independently summarize and systematize the acquired; b) identify areas for further study of the material: where and for what purpose it may be used or useful.

The active introduction of technologies for the development of critical thinking in lessons should contribute to the formation of students’ speech

and thinking skills, stimulate the development of their creative abilities, create a complex of skills to operate in educational categories, improve the ability to logically and clearly formulate and communicate clearly and clearly.

C. Terno [19] notes in his work that, in order for students to take advantage of their critical thinking skills, it is important for the teacher to develop a number of important qualities, including:

- willingness to plan (since thoughts are often chaotic, it is important to organize them, to decide in which sequence to express them);
- Flexibility (if a student is not ready to accept the ideas of others, he / she will never be able to generate ideas by himself / herself; flexibility allows one to wait for judgment until the student has a variety of information);
- perseverance (the teacher should form a student's perseverance in the tension of mental forces, so that when faced with a difficult task, the students do not decide to postpone its indefinitely);
- willingness to correct their mistakes (make the right conclusions for themselves, use the mistake to continue learning);
- awareness (ability to observe in the process of mental activity, to follow the course of reasoning);
- Finding compromise solutions (it is important that other people make the decisions they have made, otherwise they will remain at the level of expression).

The main result of the training should be students' ability to think critically. To do this, students must learn the basic principles that characterize this process, and be able to put them into practice. Each of these principles can be considered as a mental skill: identifying and denying assumptions; verification of actual accuracy and logical consistency; exploring alternatives; consideration of the context.

Thus, for the development of critical thinking, the teacher must provide the following conditions: create problematic situations in the learning process; propose problematic tasks and organize a dialogue in the process of solving them; familiarize students with the principles, strategies, and procedures of critical thinking; create choice situations; involve in reflection reflections with further reflection; to give students the right to make mistakes, to learn how to analyze them, to model error correction situations. Compliance with these requirements will ensure independence, validity, awareness, reflexivity, controllability and self-organization of thinking, that is, critical thinking of students will develop.

They will also actively contribute to the development of critical thinking STEM programs that are developed in the following areas: integrated, cross-curricular curricula; robotics and engineering; “Smart devices” of the Internet of Things; 3D modeling. For example, robotics lessons are, first and foremost, teamwork where children work in pairs: collecting work, writing a program. Working in pairs gives students time to think, to share ideas with a partner, and only then to bring them to life. Teamwork promotes communication skills, the ability to speak, the ability to persuade and debate. Also, this form of work allows students to acquire the skills of collaboration, to master the ability to speak and actively listen, and therefore through the lessons of robotics is formed critical thinking.

Early involvement of students in STEM education can support not only the development of critical, creative, creative thinking and the development of a researcher’s competence, but also contribute to a better socialization of the individual, as he develops skills such as collaboration, effective communication, creativity. Critical thinking and creativity can breathe new life into any scientific and technological project, show it not yet opened opportunities. Moreover, those who are able to go beyond technical skills and think outside the box can invent something completely new in many areas of human activity. Critical thinking is a higher-order thinking characterized by independence, purposefulness, validity, and reflectiveness.

It is possible to form critical thinking both purposefully and in each lesson, but in any case, the process of knowledge acquisition becomes the starting point rather than the end point of the thought process.

In order to develop students’ critical thinking, it is possible to apply such current forms of STEM-learning as: flipped learning; laboratory work; design works; diving; paired and group forms of work, etc.

Flipped learning is a learning process technology that assumes students use a variety of gadgets to listen and watch video lessons, learn additional sources on their own (after hours), and then discuss new concepts and ideas together in the classroom, and help the teacher apply the knowledge they have learned, in practice. The learning organization encourages students to learn from each other. It is an effective means of implementing the learning process, which is based on the use of modern information and telecommunication technologies that allow you to learn from a distance without direct, personal contact between the teacher and the student.

The method of projects, as a form of STEM-learning, is based on the development of students’ cognitive skills, the ability to self-construct their knowledge and navigate the information space, improve critical thinking, and focus on the result of their own activities. Also, the project method gives

the opportunity to develop the following competencies: goal setting and achievement; teamwork; critical thinking; the ability to learn throughout life.

The implementation of the project method in the educational process is one of the effective ways of improving the quality of students' training. The use of project technology as a means of realizing STEM education provides ample opportunities for integrating students' knowledge in various subjects in the course of solving real problems, thereby conditioning their practical use, as well as generating new ideas, forming all the necessary competencies.

Critical thinking skills and in-depth scientific knowledge gained through STEM training allow a student to grow as an innovator — the engine of human development. It is impossible to invent something completely new, just knowing the known facts. They need to be able to analyze, combine, critically evaluate and apply them. Teaching is not about passing on knowledge from a teacher or a book to students, it is a way of finding unconventional innovative solutions and raising awareness. This is what STEM education is all about, because it not only focuses on the science component of learning and innovative technologies, but also actively develops the creative component of personality and critical thinking.

4 Conclusions

To summarize, we note that the phenomenon of critical thinking is defined as the high ability to systematize and analyze information through the lens of a personal-psychological approach in terms of logic. Critical thinking promotes careful reflection, whereby the person makes the right decisions, is not manipulated, is able to defend his position, appeal to his own experience, independently evaluate the phenomena of the surrounding reality.

Critical thinking in philosophy is seen more broadly than as a component of STEM competencies. In general, the literature can distinguish several approaches to the understanding of critical thinking, which can be called: psychological-pedagogical, logical-methodological and scientific; But in STEM education, critical thinking is considered to be a purely logical and methodological aspect. That is, the ability to analyze and synthesize, compare, concretize, summarize, formulate conclusions.

Critical thinking is not just a thinking process similar to logical, analytical, creative and other thought processes. It is the thinking that, at the outset, is shaped not only by the ability to use a few percent of the

brain's operational capabilities, such as consciously analyzing, synthesizing, drawing conclusions, seeing the problem from different angles, but also the position, the spiritual fullness of the individual.

The multifaceted nature of the problem of critical thinking development explains the existence of various interpretations; This study does not exhaust all aspects of the problem and therefore needs further investigation.

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