"PAISII HILENDARSKI" UNIVERSITY OF PLOVDIV
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# FORMATION OF PRACTICAL KNOWLEDGE AND SKILLS IN STUDENTS THROUGH STEM TRAINING (BIOLOGY AND HEALTH EDUCATION – 7th GRADE)

## ABSTRACT
## of a dissertation

**for awarding the educational and scientific degree "doctor"**

field of higher education **1. Pedagogical sciences,**
professional direction **1.3. Pedagogy of training in ...,**
doctoral program **Teaching methodology in biology**

Supervisor:
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The dissertation work was discussed and directed for defense at a meeting of the Department of Botany and Biological Education at the Faculty of Biology of Paisii Hilendarski University, held on 14.06.2024.

The dissertation is structured in an introduction, three chapters, conclusion and conclusions, contributions, publications on the topic, bibliography and 6 appendices. The total volume is 245 pages, of which 166 are main text. 58 tables and 63 figures are included. The list of literary sources includes 140 sources, of which 38 in Cyrillic, 78 in Latin and 24 Internet sources. The list of author publications consists of 5 titles.

The materials for the defense are available in the "Development of the academic staff and doctoral studies" department at the "Paisii Hilendarski" University of Plovdiv and in the Central Library of the "Paisii Hilendarski" University of Plovdiv.

The defense of the dissertation will take place on 17.09.2024 at 11:00 a.m. in the meeting hall of the "Compass" conference center, Rectorate Building of the "Paisii Hilendarski" University of Plovdiv, 24 "Tsar Asen" Street, at a meeting of the scientific jury composed of:

**Prof. Zhelyazka Dimitrova Raykova, PhD**
**Assoc. Antoaneta Anastasova Angelacheva, PhD**
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## INTRODUCTION

All of the pressing issues facing our world (climate change, disease, energy resources, etc.) are somehow related to science, technology, engineering, and math (STEM) (Grand-Meyer et al., 2022). STEM-related are also the fastest growing professions. Artificial intelligence and machine learning specialists top this list, followed by sustainability specialists, robotics engineers, data analysts and scientists[1].

Much of modern education is devoted to preparing students for jobs that are rapidly becoming obsolete. The wider adoption of technology is linked to changing skills in demand in jobs in the coming years, and skills shortages will continue to be high. A survey of employers notes serious gaps between the skills their workforce needs and the skills their new hires have. Intellectual and practical skills such as critical thinking, analytical reasoning, complex problem solving, teamwork, information literacy and innovation, oral and written communication, and creativity are ranked significantly higher than technological skills and quantitative reasoning (Felder & Brent, 2016).

According to a report by the World Economic Forum, the ten most valuable and in-demand job skills of tomorrow are:

1. Analytical thinking and innovation
2. Active learning and learning strategies
3. Complex problems-solving
4. Critical thinking and analysis
5. Creativity, originality and initiative
6. Leadership and social influence
7. Technology use, monitoring and control
8. Technology design and programming
9. Resilience, stress tolerance and flexibility
10. Reasoning, problem solving and ideation

These skills of the future are grouped into four categories:

- Problem-solving (1, 3, 4, 5 and 10)
- Self-management (2 and 9);
- Working with people (6)
- Technology use and development (7 and 8)[1]

One of the roles of the school is to prepare students for successful future life and professional realization, forming in them the practical skills of tomorrow. According to the latest PISA 2022 results, however, regardless of the knowledge that Bulgarian students possess (according to our curricula), they encounter great difficulties in applying it in practice in different, close to real situations (what PISA emphasizes)[2].

Despite the competency-oriented curricula, their restructuring based on certain principles is in the offing to make them more framework and adaptive, which in the long run will not only increase the performance of Bulgarian students in PISA-type studies, but will also prepared much better for life and for their realization in the labor market.

In this regard, STEM education is gaining attention because of its great importance, from improving life skills and career development to expanding the global economy.

The preparation and implementation of quality STEM training is another challenge for teachers, as drivers and implementers of any change in education. But are teachers teaching STEM effectively? Are there enough teachers prepared and confident in teaching STEM? Are there enough developed STEM learning resources to help teachers? The lack of a definite positive answer to these questions and the need for a real change in the direction from memorization and reproduction of knowledge to the formation of skills for their application and skills of the 21st century determine the relevance of the problem and are grounds for undertaking pedagogical research related to the formation of practical knowledge and skills in students through STEM education in biology and health education in the 7th grade.

## FIRST CHAPTER. THEORETICAL ANALYSIS OF THE LITERATURE ON THE PROBLEM

### 1. STEM, i-STEM and STEAM – definition and learning models

The first chapter provides a brief historical overview of the development of STEM and examines the characteristics of STEM disciplines and their integration. Conceptual frameworks, models and good pedagogical practices for STEM integration are analyzed.

STEM is an acronym for Science, Technology, Engineering and Mathematics. The initiative was created in the 1990s by the US National Science Foundation (NSF) in response to a policy agenda based on professional and economic needs. Initially, STEM was perceived by teachers as S.T.E.M. – separation of the four disciplinary areas, not their integration. There followed a period of focusing on traditional science and math teaching and ignoring the technology and engineering components – S.t.e.M. (Blackley & Howell, 2015). STEM is not a simple unification under "one hat" of the four disciplines (Obukhov & Lovyagin, 2020; Velkova and Dobrev, 2020). This statement is also supported by Kotseva & Gaidarova (2019) , according to which the idea of STEM “will succeed if the idea of i-STEM – integrated STEM education succeeds. This idea is not intended to cancel the education of the individual disciplines, but on the contrary - to support and supplement it through all formal and informal means wherever possible." (Kotseva & Gaidarova, 2019: 487). "If science, technology, engineering and mathematics can be represented as parts of the human body, science is the skeleton and muscles, engineering is the brain, technology is the hands, and mathematics is the heart and blood. Therefore, these separate disciplines are actually closely related to each other…" (Akgun, 2013: 66). Moore & Smith (2014) and Bryan et al. (2016) consider three forms in the integration of STEM in the classroom: contextual integration, content integration, and supporting content integration, and Vasquez (2014) distinguishes four levels of integration between academic disciplines: disciplinary, multidisciplinary, interdisciplinary and transdisciplinary.

The idea of i-STEM is also spreading to include disciplines outside the STEM group. More often, the addition of "A" in the acronym is associated with the addition of the arts (in English Arts). Creative components and creativity are equally important in the learning process to engage students to increase their understanding and skills in innovation. Employers are looking for creative problem solvers, and creativity is a key skill in the technology-driven economy of the twenty-first century (Hunter & Sydow, 2016; Jolly, 2017; English, 2017). The inclusion of "A" in STEAM is also interpreted as the integration of all other (in English All) academic disciplines (Moore & Smith, 2014; Kotseva & Gaidarova, 2019).

The literature review on the topic is impressive with the range and scope of what is defined as STEM/i-STEM. Definitions range from simply referring to the four STEM disciplines, through educational approaches at the intersections of any number of the four disciplines, to connecting all four STEM disciplines in an integrated manner. In item I.3, 27 definitions are systematized (table 1, p.18 from the dissertation). United around integration, the definitions reflect different components of the learning system – procedural, target, organizational (Fig. 5, p. 24 from the dissertation).

Based on the analysis and summary of the definitions, for the purposes of this study, we propose the following definition:

Integrated STEM learning is a discreet teacher-directed process of active learning, at which students purposefully apply integrated science and mathematics knowledge, skills, and methods and incorporate the practices of technology and engineering design to create abstract and concrete technology artifacts in solving real-world problems and engineering challenges.

The lack of consensus on the definition of STEM learning is understandable, given the complex nature of the learning process. However, according to Bybee (2013) defining STEM is the easy part and implementing STEM learning on a large scale is the bigger challenge.

The literature review identified four instructional models for STEM integration.

- Learning by Design™ model – project-based, inquiry-based learning through which students learn scientific content and skills in the context of realizing an engineering challenge (Fig. 8, p. 30 from the dissertation) (Kolodner, 2002).
- Model 5E, developed by the Biological Sciences Curriculum Study (BSCS) and based on a constructivist view of learning, provides a planned sequence of instruction that places students at the center of their learning experience, encouraging them to explore, build their understanding of scientific concepts and relate these understandings to other concepts (Bybee et al., 2006; Bybee, 2009). The name of the model is an acronym of the initial letters of its five phases – Engagement, Exploration, Explanation, Elaboration and Evaluation.

According to some authors (Barry, 2014; Yata et al., 2020) the BSCS 5E learning model does not fully represent the engineering design process and only provides teaching and assessment of a single subject because the model is science-based and highly related to the content and activities of individual subjects. This initiated the emergence of two other models:

- Model 6E Learning byDeSIGN ™ (Barry, 2014), which adds an "e" phase (cycle) called eNGINEER, in which students really design and model like engineers. The framework acquires types Engage, Explore, Explain, eNGINEER, Enrich and Evaluate.
- Model PIRPOSAL (Wells, 2016), which is centered around the process of moving from convergent to divergent questioning, involving a series of continuous transitions between available knowledge - "what I know" and missing knowledge - "what I need to know", which ultimately leads to design decisions. The name of the model is an abbreviation of the initial letters of the eight phases (Fig. 9, p.35 in the dissertation) - Problem identification, Ideation, Research, Potential solution, Optimization, Solution evaluation, Alteration and Learned outcomes.

The literature review of examples of STEM practices made in item I.4.4 showed that the most used for lesson design is the 5E model. In some practices, these are a series of benchmark lessons in a project-based STEM module that culminates in a project whose product is a technological artefact (Walton & Caruthers (2015), Ofghe at al. (2019), Dodson-Snwoden (2019), Pollard & Profitt (2019), Wilhelm et al. (2019). Much of the reference lessons lack engineering design, but learning activities are designed so that students actively predict, test, model, calculate, analyze and graph data, formulate conclusions. The concrete implementation of integrated STEM learning is associated with the application of active learning and teaching strategies (active learning). Related approaches, methods and their characteristics are discussed in item I.5.

2. **4C 21st century skills**

Internationally, no clear and unique definition of "skills (competencies) of the 21st century" has been presented and accepted.

A definition by the Asia Pacific Economic Cooperation (APEC) Organization defines 21st century competencies as the knowledge, skills and attitudes required by a person to be competitive in the 21st century workforce, to participate appropriately in increasingly diverse society, to use new technologies and to cope with rapidly changing workplaces (Scott, 2015).

The competencies of the 21st century are defined by Voogt & Roblin (2010) as an overarching concept of the knowledge, skills and attitudes that citizens need to contribute to an educated society.

According to the European reference framework, key competences are a combination of knowledge, skills and attitudes that every person needs for personal fulfillment and development, employability, social inclusion, sustainable lifestyle, successful life in peaceful societies, organizing life in a healthy way and active civil participation[3].

The different frameworks also use different terminology of the types of 21st century competencies (Voogt, & Roblin, 2010). In table 3, p. 53 of the dissertation the terminology in the European reference framework and the Partnership for 21st century skills framework (P21) developed in the USA are compared. The first set of 21st century skills in the P21 framework focuses on learning and innovation skills. These are known as the 4Cs:

- Critical thinking and problem solving (expert thinking)
- Creativity and innovations (application of imagination and ingenuity)
- Communication
- Collaboration

The expected results of the formation of these skills are systematized in the table. 4, p. 56 of the dissertation, achieving them unlocks lifelong learning and creative work. Critical thinking and problem solving are considered the new foundations of learning in the 21st century.

## SECOND CHAPTER. PEDAGOGICAL RESEARCH DESIGN AND METHODOLOGICAL MODEL FOR IMPLEMENTING STEM EDUCATION

1. **Research planning and organization**

In item II.1.1, the purpose, object, subject, hypothesis and tasks of the research are formulated.

➢ **Purpose** of the study:

Development and testing of a methodological model for the application of STEM education in the study of curriculum content in biology and health education 7th grade

➢ **Object** of the study:

The learning process of biology and health education 7th grade by applying STEM learning.

➢ **Subject** of the study:

The students' practical knowledge and skills as a result of the implementation of STEM education in the subject of biology and health education.

➢ **Research hypothesis**:

If the methodological model is applied to STEM education in biology and health education in the 7th grade, it will increase the level of students' practical knowledge and skills in biology and health education and their motivation, as well as develop 4C skills of the 21st century.

➢ **Tasks**:

1. To conduct a literature survey of research in the field of STEM education, the features and possibilities for its application.

2. To analyze the teaching content of biology and health education 7th grade in order to find opportunities for applying STEM education.

3. To develop a methodological model for the implementation of STEM education in biology and health education 7th grade.

4. To develop didactic materials and technology for conducting STEM training for students.

5. To prepare and implement a pedagogical experiment related to the application of STEM education in biology and health education.

6. To compile instruments - tests and surveys to measure the practical knowledge and skills of the 7th grade students and their attitude towards the study of biology and health education in a STEM environment.

7. To analyze the results of the pedagogical experiment and formulate conclusions about the influence of STEM education on the formation of practical knowledge and skills among students.

In item II.1.2.1. the methods of pedagogical research are presented:

➢ Theoretical:
- analysis of literary sources;
- analysis of good pedagogical practices and experience.

➢ Empirical:
- analysis of the educational content in biology and health education 7th grade
- didactic experiment;
- tested;
- polling;
- statistical processing and data analysis.

The analysis of the educational content includes the analysis of mandatory educational documentation related to the subject of biology and health education at the junior high school stage of the basic level of education and of concepts and areas of competence in the normative documents. This is how the topics included in the didactic experiment were determined.

The didactic experiment is a method in which specific conditions are created in which the studied phenomenon or process takes place. It takes place in the conditions of school education after the theoretical study. The basis for its application is the constructed methodological model, developed as a result of the theoretical analysis of literary sources and pedagogical practices and experience (Bizkov & Kraevski, 2007; Stavreva, 2010).

Testing is a method of pedagogical diagnostics that objectively, reliably and validly measures the learning outcomes that are evaluated, interpreted and used by subjects participating in the learning process. (Tsanova & Raycheva, 2012). The didactic test is a set of questions and tasks related to a certain educational content and constructed according to certain goals and certain procedures (Tafrova, 2007). The toolkit for establishing the level of acquired knowledge and formed skills in our study includes two criterion tests: a pre-test to establish the level of knowledge and skills before applying experimental STEM training and a post-test to report them after applying experimental training. The content of the tests, the specification of questions and indicators, as well as the number of points for each question are shown in Appendix 3 (pre-test) and Appendix 4 (post-test), and the results are presented in Chapter Three of the dissertation. The tests are subject to expert evaluation. Experts assess the content validity of each task, i.e. whether it actually measures the same purpose for which it was intended and ascertain whether the task has structural and stylistic flaws that would reduce its effectiveness. Biology and health education teachers have been invited as experts: Krasimir Vitlarov PhD, "Vasil Levski" Primary school, Plovdiv; Zvezdelin Malamov, "St. Kliment Ohridski" Secondary school, Plovdiv; Sanya Peneva, Primary School "Yane Sandanski", Plovdiv; Milena Atanasova, "Knyaz Alexander I" Primary School, Plovdiv and Nikolay Kochev "Hristo Botev" Primary school, Krumovo. Specialists are provided with cards for expert assessment (Appendix 5 to the dissertation). All experts gave a positive assessment of the quality of the tasks and their compliance with the measured criteria and the expected results according to the curriculum.

A survey is a system of questions and answers to them, which are given to the surveyed persons to express an opinion or attitude. The main tool in the survey is the survey card. The survey can be applied both to study the attitude towards educational knowledge and to the cognitive activities planned and carried out by the teacher (Tsanova & Raycheva, 2012). In our research, standardized surveys of participants in the experimental training are also conducted. With numerical scales, the degree of interest in certain topics and the desire to work with the students participating in the experimental training are determined. The survey cards provide an opportunity for learners to express their attitudes regarding the impact of STEM education on the formation of practical skills in communication and collaboration, problem solving and critical thinking. The survey cards used in the research are presented in Appendix 2, and the results of the survey - in Chapter Three of the dissertation.

Mathematical-statistical methods serve to interpret the results in the context of the researched problem and reveal connections and regularities in the studied objects, in accordance with the applied pedagogical effects. The choice of the appropriate methods of analysis is made based on the type of: distribution of the populations of the compared samples, uniformity or difference in the variances of the groups, the set goal and the type of the hypothesis, the evaluation scale, etc. The Kolmogorov-Smirnov test was used to check the normality of the data distribution for the number of points awarded for questions, indicators and criteria for both groups. In this particular case, none of the data distributions are normal, suggesting the use of a non-parametric Mann–Whitney test to test hypotheses of a difference between two independent samples. The reliability coefficient of the two tests was calculated using Cronbach's alpha (**α**) coefficient to measure the internal consistency between the variables. The presentation of the results of the conducted analysis was carried out through frequency tables, linear and bar charts in Chapter Three of the dissertation.

In item II.1.2.5. the criteria and indicators for reporting the results of the experiment are described (table 1). The cognitive levels of Bloom's taxonomy revised by Anderson and Krathwohl (Anderson & Krathwohl, 2001 cited in Ivanov, 2006; cited in Gaidarova & Georgiev, 2018: 6; cited in Felder & Brent, 2016: 31). In it, unlike the original taxonomy, cognition has two dimensions: knowledge and cognitive process. Knowledge is subject matter content and has four categories: factual, conceptual, procedural, and metaknowledge. The cognitive process dimension shows what needs to be done with the subject content. The cognitive process reflects different forms of thinking, and since thinking is an active process, verb forms are used. This dimension has six categories as in the original taxonomy, but they have been renamed and converted:

VI. Creating – combining elements to form a new, coherent whole or to make an original product.

V. Evaluating - making judgments based on criteria and standards

IV. Analyzing – breaking down material into its component parts and discovering how the parts relate to each other and to the overall structure or purpose

III. Applying - using what has been learned, applying principles, rules, concepts, methods in given situations.

II. Understanding - presenting the meaning of what is studied through various forms, interpretations, comparisons, including oral, written and graphic communication
I. Remembering – retrieving relevant knowledge from long-term memory[4].

The six levels are associated with relevant thinking skills, which are divided into lower-level (lower-rank) thinking skills – remembering, understanding and applying, and higher-level (higher-rank) skills – analyzing, evaluating and creating (Gendjova, 2012; Felder & Brent, 2016). Our focus is primarily on the formation of higher-order skills—analyzing, evaluating, and creating—as well as application skills, which are the third (highest) level of lower-order skills.

***Table 1.*** *Criteria, indicators and toolkit for reporting the acquired practical knowledge and formed practical skills and the attitudes formed in students regarding motivation and 4C skills of the 21st century*

| **Criteria** | **Indicators** | | **Toolkit**<br>Question no |
|---|---|---|---|
| **Remembering** | Remembers and reproduces scientific knowledge. | | T1*: 1.2; 2.2<br>T2*: 1.3 |
| **Understanding** | Explains, recognizes and compares facts, concepts, processes. | | T1: 1.1; 1.3; 2.1<br>T2: 1.1; 1.2; 3.3; 3.4 |
| **Applying** | Application skills | Applies scientific knowledge and methods to new situations. | T1: 2.6; 2.7<br>T2: 3.1; 4.3 |
| | | It applies healthy lifestyle rules and supports activities to protect personal and public health. | T1: 1.6<br>T2: 2.2 |
| **Analyzing** | Analytical skills | Analyzes and interprets data (schemes, tables, graphs, diagrams, text) and makes conclusions, predictions. | T1: 1.4; 2.4; 2.8<br>T2: 2.1; 4.1; 4.2 |
| | Problem solving skills | Identifies (defines, formulates) a problem. | T1: 2.5<br>T2: 1.4 |
| | | Establishes causal relationships between variables. | T1: 2.3<br>T2: 3.2 |

| | | | |
|---|---|---|---|
| **Evaluating** | Evaluation and critical thinking skills | Evaluates alternative claims, viewpoints, and argues, supports his choice with scientific evidence. | T1: 1.5<br>T2: 4.4 |
| **Creating** | Creation skills | Plans, design, construct, formulate, offer solutions, generate ideas, apply creativity and innovation, and create an author's product. | T1: 1.7<br>T2: 4.5 |
| **Motivation to the students** | Interest | | An**: 12; Asf**: 1 |
| | Desire for practical work | | As: 2 |
| | Willingness to seek and receive information | | An: 10 |
| | Making sense of learning | | An: 13; 14 |
| **Formation of 4C skills of the 21st century (learning and innovation skills)** | Collaboration skills | | An: 3; 7 |
| | Communication skills | | An: 4 |
| | Critical thinking and problem solving skills | | An: 5; 6<br>T1: 1.5; 2.5; 2.3<br>T2: 4.4; 1.4; 3.2 |
| | Creativity and innovation skills | | T1: 1.7; T2: 4.5 |

***T1** – pre-test; **T2** – post-test
****An –** a survey of attitudes towards a STEM lesson/project; **Asf** – survey-self-assessment

## 2. Methodological model for implementing STEM education

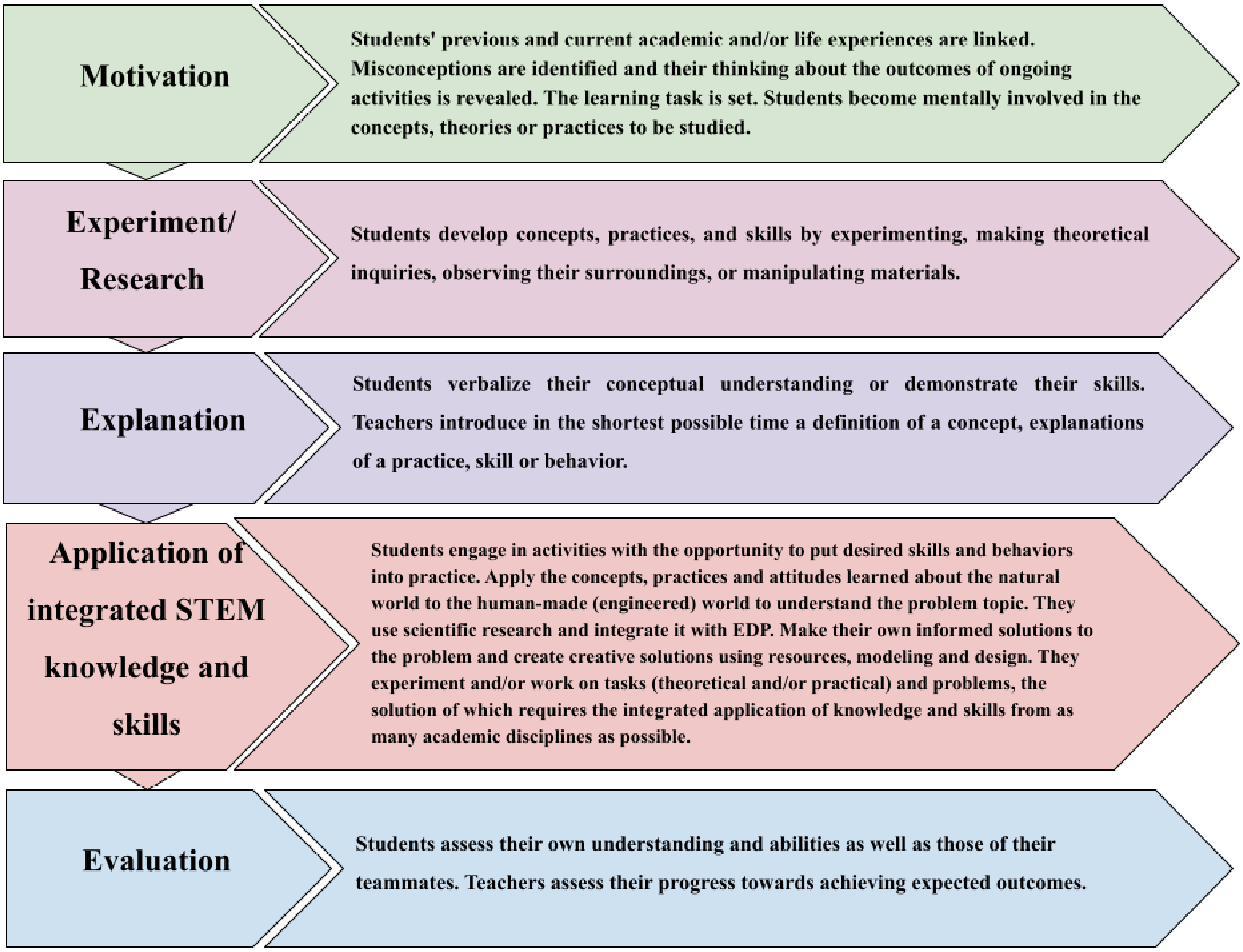


***Figure 1.*** *Model for implementing STEM education (ME/REAE model)*

In item II.1.2.3. a methodological model for implementing STEM education is proposed, which is influenced by the BSCS 5E models (Bybee et al., 2006; Bybee, 2009) и 6E Learning byDeSIGN ™ (6E Learning by Design) (Barry, 2014) for the integration of STEM, described in detail in item I.4.2.2 and item I.4.2.3 of Chapter One of the dissertation.

The activities characteristic of the eNGINEER phase of the 6E model are integrated into the Elaboration phase of the BSCS 5E model. The phase is called "Application of integrated STEM knowledge and skills" and allows teachers to plan and involve students in a new experiment and/or in an engineering challenge and/or in solving theoretical and practical tasks requiring the application of knowledge and skills from STEM disciplines. To name some of the phases, we use not mechanically translated, but analogous terms from bulgarian methodical science and practice, which have gained wide distribution and citizenship for better understanding and continuity. With this naming of the phases of the model, the abbreviation ME/REAE is obtained (fig. 1)

## 3. Conducting the research

The stages of the pedagogical research are presented in table 2.

***Table 2.*** *Stages of pedagogical research*

| Stages | | Aims | Students |
|---|---|---|---|
| 1. Planning and organization<br>m. III-IX 2021. | | Development of the methodological and methodical part of the concept and the specific organization of the research | – |
| 2. Conduct | 2.1<br>Preliminary experiment<br>2021/2022 | Approbation of the developed didactic and diagnostic tools and research in part of the developed methodology. | 114<br>7th grade at Yane Sandanski Primary School, Plovdiv |
| | 2.2<br>Main experiment<br>2022/2023 | Realization of the planned active pedagogical impact, tracking changes in the object of research and carrying out diagnostic measurements to establish the degree of changes and changes that have occurred | 92<br>7th grade at "Yane Sandanski" Primary School, Plovdiv, separate EG and CG |
| | 2.3<br>Final experiment<br>2023/2024 | Confirming the effectiveness of the experimental training, performing the final diagnostic measurements of the state of the object, additional impacts and measuring the changes that have occurred. | 98<br>7th grade at "Yane Sandanski" Primary School, Plovdiv, separate EG and CG |
| 3. Presentation and analysis of results, development of dissertation work<br>m. I-III 2024. | | Summarizing and analyzing the results. Popularization of pedagogical research results. Dissertation design | – |

# CHAPTER THREE. ANALYSIS OF THE RESULTS OF THE PEDAGOGICAL EXPERIMENT TO RESEARCH THE QUALITIES OF THE METHODOLOGICAL MODEL

## 1. Analysis of the results of the preliminary experiment

Section III.1 presents the results of aposteriory analysis of the two tests and their reliability data. Without forgetting the purpose of the criterion tests - to measure whether and to what extent the learning objective has been achieved, their final versions are compiled after careful analysis of data on success rate (difficulty), discriminative power and effectiveness of distractors established by applying the technique for normative tests. Although these indicators are not decisive in criterion tests, the values obtained in combination with the categorical positive assessment of the content validity of the questions given by the experts make the tests we have compiled suitable for use for research purposes.

Cronbach's alpha (**α**) values for the two tests in our study are presented in the table 3.

***Table 3***. *Reliability coefficient of pre- and post-test*

| Test | Cronbach's Alpha Based on Standardized Items | N of Items |
|---|---|---|
| **Pre-test (entry)** | 0,742 | 15 |
| **Post-test (exit)** | 0,788 | 15 |

The results (**α**>0.70) indicate acceptable test reliability for practical purposes. It allows comparisons of EG and CG results from the two tests – before and after the pedagogical impact.

### 2. Analysis of the results of the main experiment

In the main experiment, 92 students from 4 classes in the 7th grade of "Yane Sandanski" Primary School, Plovdiv, participated. Two groups were formed: a control group, which is in traditional learning conditions, and an experimental group, with which STEM learning takes place (table 4)

***Table 4***. *Parameters of groups in the main experiment*

| Group | Class | Boys | Girls | Total students |
|---|---|---|---|---|
| Control (CG) | 7.a and 7.b | 24 | 22 | 46 |
| Experimental (EG) | 7.v and 7.g | 21 | 25 | 46 |

### 2.1. Analysis of test results

CG and EG achieve very close results for the average total number of points (11.65 points for CG and 11.37 points for EG), resp. average success rate. The performance of students from both groups on questions is presented in fig. 2.

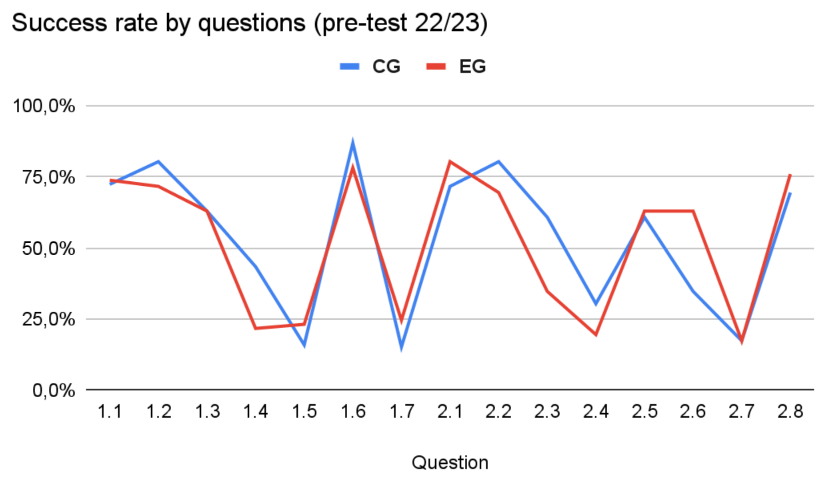


***Figure 2***. *Graphically presented data on success rate by pre-test questions in the main experiment*

We formulate the following working hypothesis: $N_0$– there is no statistically significant difference in the results of the entry level of students from the control and experimental groups, i.e. the observed difference is due to random causes. $N_1$ – there is a statistically significant difference in the results of the entry level of students from the control and experimental groups, i.e. the observed difference cannot be explained by random reasons, but has a regular character. The results of a non-parametric Mann-Whitney test for hypothesis testing are presented in table 5. The values of sig.(p-value)<0.05 indicate the presence of statistically significant differences according to the relevant indicator for the two studied groups.

***Table 5.*** *Statistical significance of results by pre-test questions in the main experiment*

| **Question** | **1.1** | **1.2** | **1.3** | **1.4** | **1.5** | **1.6** | **1.7** | |
|---|---|---|---|---|---|---|---|---|
| p-value | 0,865 | 0,208 | 1,000 | 0,027 | 0,117 | 0,274 | 0,050 | |
| **Question** | **2.1** | **2.2** | **2.3** | **2.4** | **2.5** | **2.6** | **2.7** | **2.8** |
| p-value | 0,331 | 0,231 | 0,013 | 0,231 | 0,831 | 0,007 | 1,000 | 0,484 |

The obtained results confirm the null hypothesis $H_0$, therefore at the beginning (entry) of the experiment, the two groups are equal.

Four of the criteria (remembering, understanding, applying and analyzing) and their indicators are measured by means of two or more test questions. That is why a clearer comparison of the results of CG and EG can be made from the data on obtained points and success rate, presented in detail in the table. 24, p. 108 of the dissertation.

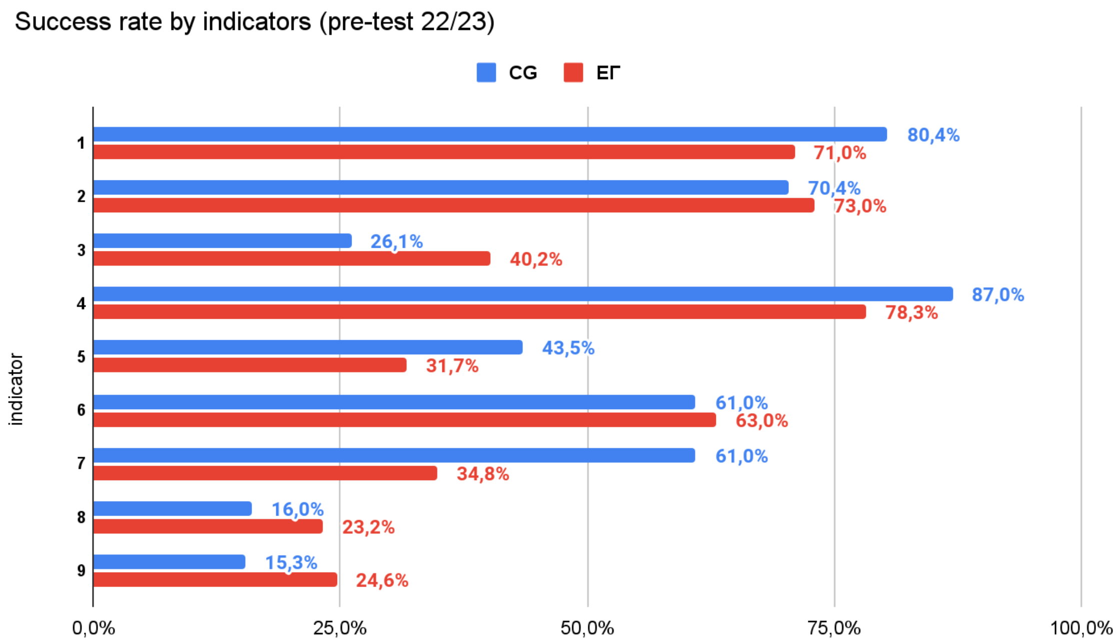


***Figure 3.*** *Graphical representation of success rate by indicators of pre-test in the main experiment*

Data from the Mann-Whitney test (table 6) confirm the null hypothesis $H_0$, that there is no statistically significant difference in the results of the entry level indicators of the control and experimental group students.

***Table 6.*** *Statistical significance of results by indicators of pre-test in the the main experiment*

<table>
<tr><td>Indicator</td><td>1. Remembers and reproduces scientific knowledge</td><td>2. Explains, recognizes and compares facts, concepts, processes.</td><td>3. Applies scientific knowledge and methods to new situations.</td><td colspan="2">4. Implements rules for a healthy lifestyle and supports activities to protect personal and public health.</td></tr>
<tr><td>p-value</td><td>0,170</td><td>0,884</td><td>0,018</td><td colspan="2">0,274</td></tr>
<tr><td>Indicator</td><td>5. Analyzes and interprets data from schemes, tables, graphs, charts, text and draws conclusions and predictions.</td><td>6. Identify, define, formulate a problem</td><td>7. Establishes causal-causal relationships between variables</td><td>8. Evaluates alternative statements, points of view and argues, supports his choice with scientific evidence</td><td>9. Plans, designs, constructs, formulates, offers solutions, generates ideas, creates an author's creative product</td></tr>
<tr><td>p-value</td><td>0,020</td><td>0,831</td><td>0,013</td><td>0,117</td><td>0,050</td></tr>
</table>

The average number of points resp. the success rates of EG (15.96 points; 66.5%) after the experimental STEM training are 6.35 points (26.4%) higher than those of CG (9.61 points; 40.1%) .

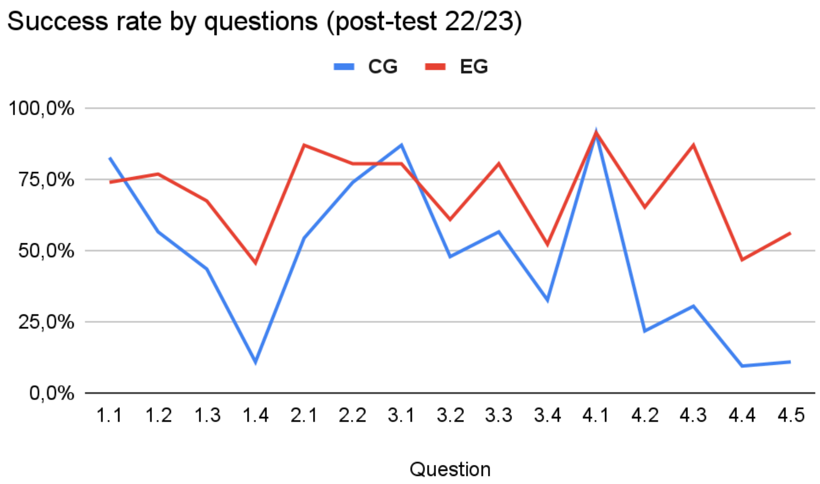


***Figure 4****. Graphically presented data on success rate by post-test questions in the main experiment*

We formulate the following working hypothesis: $N_0$ – there is no statistically significant difference in the results of the starting level of students from the control and experimental groups, i.e. the observed difference is due to random causes. $N_1$ – there is a statistically significant difference in the results of the starting level of students from the control and experimental groups, i.e. the observed difference was due to the applied STEM training. Data from the Mann–Whitney test (table 7) show that the observed differences in the scores of CG and EG students on questions are statistically significant ($p<0.05$) for nine of the questions. Among them are almost all the questions that measure the higher-order cognitive skills of analyzing, evaluating, and creating, and on these nine questions EG shows better results. Most of the questions, where no statistically significant difference ($p>0.05$) was observed, measured skills from the lower cognitive levels - understanding. Among them are the only two questions on which CG has a higher point score.

***Table 7****. Statistical significance of results by post-test questions in the main experiment*

| **Question** | **1.1** | **1.2** | **1.3** | **1.4** | **2.1** | **2.2** | **3.1** | |
|---|---|---|---|---|---|---|---|---|
| p-value | 0,315 | 0,008 | 0,022 | 0,000 | 0,001 | 0,459 | 0,400 | |
| **Question** | **3.2** | **3.3** | **3.4** | **4.1** | **4.2** | **4.3** | **4.4** | **4.5** |
| p-value | 0,212 | 0,014 | 0,059 | 1,000 | 0,000 | 0,000 | 0,000 | 0,000 |

From the analysis of Mann-Whitney test data, it can be concluded that the better EG scores are statistically significant and due to applied

STEM training, and the lower and equal CG scores are not statistically significant. This gives us reason to reject the null hypothesis $H_0$ and accept the alternative $H_1$.

The advantage of EG in terms of results after applied STEM training is clearly observed in the data on points and success rate (table 30, p.118 of the dissertation) according to the indicators described in the specification of the post-test.

The data from the Mann-Whitney test (table 8) show that the observed differences in the results of CG and EG students on indicators are statistically significant ($p<0.05$) for seven of the nine indicators, and only for two of them the difference no statistically significant difference ($p>0.05$). This gives us reason to reject the null hypothesis and accept the alternative $H_1$, that there is a statistically significant difference in the results by indicators from baseline of students in the control and experimental groups, which is due to the implemented STEM training.

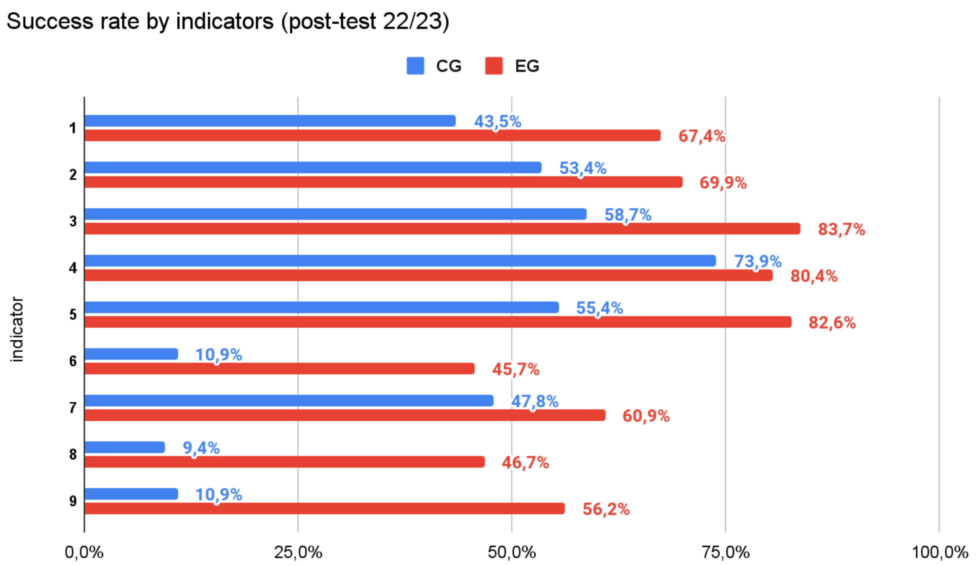


***Figure 5****. Graphical representation of success rate by indicators of post-test in the main experiment*

***Table 8.*** *Statistical significance of results by indicators of post-test in the the main experiment*

| **Indicator** | 1. Remembers and reproduces scientific knowledge | 2. Explains, recognizes and compares facts, concepts, processes | 3. Applies scientific knowledge and methods to new situations | 4. Implements rules for a healthy lifestyle and supports activities to protect personal and public health |
|---|---|---|---|---|
| p-value | 0,022 | 0,000 | 0,000 | 0,459 |

| Indicator | 5. Analyzes and interprets data (schemes, tables, graphs, diagrams, text) and draws conclusions, predictions | 6. Identify, define, formulate a problem | 7. Establishes causal-causal relationships between variables | 8. Evaluates alternative claims, points of view, and argues and supports its choices with scientific evidence | 9. Plans, designs, constructs, formulates, offers solutions, generates ideas, creates an author's creative product |
|---|---|---|---|---|---|
| p-value | 0,000 | 0,000 | 0,212 | 0,000 | 0,000 |

In point III.2.1.2 and point III.2.2.2 of the dissertation, the data are also presented at higher levels of generality - by summary indicators and by criteria.

A comparison of CG and EG post-test performance data indicated that EG students who received experiential STEM instruction increase the level of formed practical knowledge and skills for application, for analysis, to solve complex problems, to evaluate and think critically, and to create. This conclusion is also confirmed by the comparison of the success rate according to summary indicators of EG before and after the implementation of the STEM training, presented graphically in fig. 6.

In the same comparison of the input/output results achieved by CG in traditional learning conditions, there is a decrease in the success rate in all indicators except application skills and analysis skills (fig. 28, p. 124 of the dissertation).

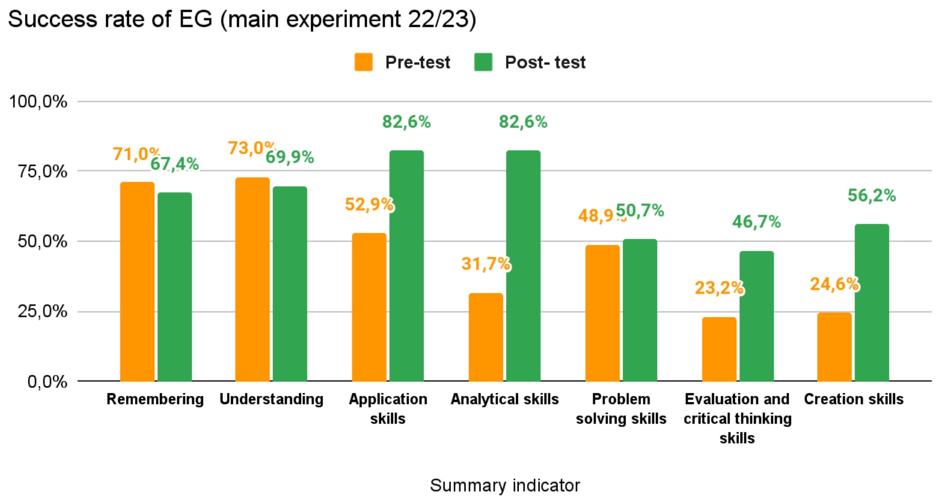


***Figure 6**. Graphical presentation of data on the success rate of EG by summary indicators from pre- and post-test in the main experiment*

## 2.2. Analysis of the results of the survey of the EG students

Through two surveys (Appendix 2 to the dissertation), the attitudes formed by the students regarding motivation and development of 4C skills of the 21st century are established according to the relevant criteria and indicators. The students answer the self-assessment survey twice - after the STEM lesson with engineering design "1,2,3 the bacteria move" and the STEM lesson with mathematical modeling "The resistant ones attack!". In this survey, two of the questions have numerical scales and determine the degree of interest and willingness to work of the students participating in the experimental training. A survey of students' interest and attitudes towards STEM education is also applied twice - after the STEM lesson with engineering design - after the STEM lesson with mathematical modeling "The resistant ones attack!" and after the STEAM project "Nth World antibacterial war". The questions in this survey are multiple-choice from five options (Yes, Rather yes, Can't decide, Rather no, and No).

Summarized data from questions in the surveys related to determining the indicators for the criteria "Motivation of students" and "Formation of 4C skills of the 21st century" are graphically presented in fig. 7 and fig. 8.

The analysis of the survey data gives us grounds to confirm that part of the working hypothesis, which is related to the positive impact of STEM education on student motivation and the learning and innovation skills (4C skills) formed in them.

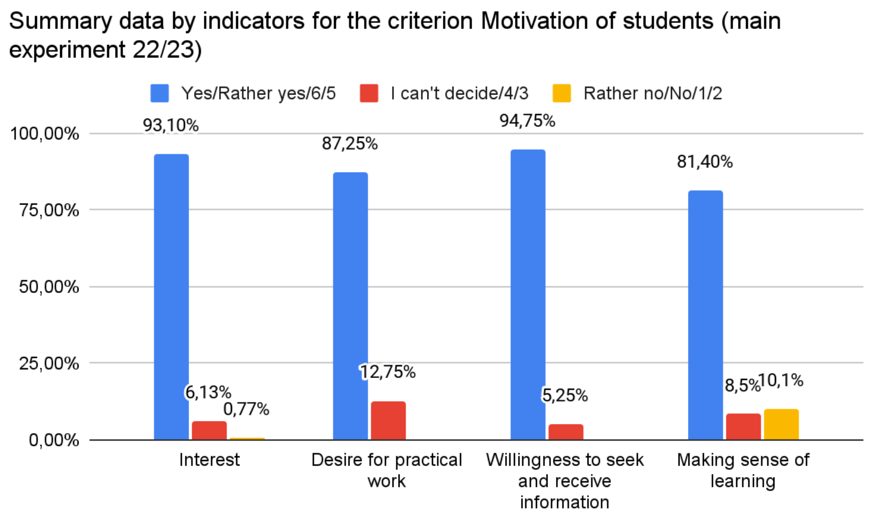


***Figure** 7. Graphical presentation of aggregated survey data by indicators for the criterion student motivation*

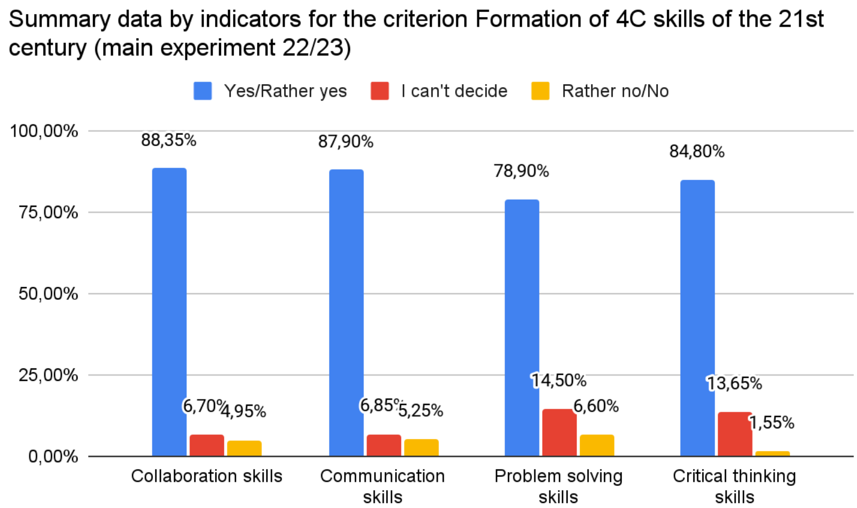


***Figure 8****. Graphic presentation of aggregated survey data by indicators for the criterion Formation of 4C skills of the 21st century*

### 3. Analysis of the results of the final experiment

In the final experiment, 98 students from 4 classes in the 7th grade of "Yane Sandanski" Primary school in Plovdiv participated, grouped into a control and an experimental group (table 9).

***Table 9****. Group parameters in the final experiment*

| Group | Class | Boys | Girls | Total students |
|---|---|---|---|---|
| Control (CG) | 7.a and 7.b | 33 | 14 | 47 |
| Experimental (EG) | 7.v and 7.g | 25 | 26 | 51 |

### 3.1. Analysis of test results

In item III.3.1. the analysis of the results of testing to determine the entry level (pre-test) in the final experiment is presented. The results of the post-test (item III.3.2.) confirm the trend that emerged during the main experiment, that the EG students who underwent experimental STEM training demonstrate higher level of formed practical knowledge and skills according to all six criteria and their indicators (fig. 51, p. 151 and fig. 52, p. 152 in the dissertation).

The results of the comparison of summary indicators of the EG students before and after the implementation of STEM education are also confirmed, showing an increase in the success rate in questions requiring application, analysis, evaluation, critical thinking and creation skills, as well as explaining and the comparison of facts, concepts, processes (fig. 53, p. 153 in the dissertation). This gives us reason to conclude that STEM education has a positive effect on the formation of students' thinking skills not only from the low levels, but also improves thinking skills of a higher order (analyzing, evaluating and creating).

### 3.2. Analysis of the results of the survey of the EG students

The summarized results of the survey (fig. 62 and fig. 63; p. 164 in the dissertation) confirm the trend that emerged during the main experiment that STEM education increases the motivation of students and develops in them 4C skills of the 21st century - the skills to learning and innovation.

## 4. Conclusion and inferences

The achieved results of the pedagogical experiment and their analysis confirm the working hypothesis that the application of the methodological model of STEM teaching in biology and health education in the 7th grade increases the level of practical knowledge and skills in biology and health education and their motivation, as well as and develops 4C skills of the 21st century.

1. The developed methodical model for implementing STEM education is effective and focuses on the formation of students' practical knowledge and skills. The model has been adapted to the conditions in the Bulgarian school and is consistent with the curriculum of biology and health education" in the seventh grade. The methodology is applied in the training on the topics "Monera" and "Protista".

2. The system of criteria and indicators developed for the purposes of the experiment, as well as a toolkit for their reporting, provides very good opportunities for diagnostics at the level of the formed practical skills and the level of motivation of the students.

3. The results of testing and surveying show higher results of students exposed to STEM education in:

- application of scientific knowledge in new situations
- implementing rules for a healthy lifestyle and supporting activities to protect personal and public health
- analysis, interpretation of data, predictions and conclusions
- problem solving
- evaluation and critical thinking
- creation and creativity
- cooperation and communication

With the formation of these practical skills of tomorrow, the students are preparing for a successful future life and professional realization.

4. The analysis of the obtained results shows that the experimental methodology in STEM education is of interest to the students and increases their motivation for learning activities.

## SCIENTIFIC CONTRIBUTIONS AND PRACTICAL SIGNIFICANCE OF THE DISSERTATION RESEARCH

1. The methodology of teaching biology and health education in the 7th grade is enriched with a developed methodical model for the application of STEM education, through which practical knowledge and skills for application, analysis, problem solving, critical thinking and creativity are formed.

2. Methodical variants of STEM lessons developed according to the model for forming practical knowledge and skills in biology and health education 7th grade and learning and innovation skills (4C skills of the 21st century) have been approved.

3. A diagnostic toolkit was constructed for evaluating the results of STEM education with the leading subject of biology and health education 7th grade.

4. The developed model can be applied to other subjects of the curriculum of biology and health education in the 7th grade, as well as being adapted for studying biology and health education in high school.

5. Separate parts of the current dissertation research have been reported at scientific conferences and published in specialized pedagogical publications.

## PUBLICATIONS ON THE TOPIC OF THE DISSERTATION

**1. Ivanova,** K., Karagyozova-Dilkova, D. (2022). "1,2,3 the bacteria move!" - a model of a STEM lesson in Biology and health education 7th grade (pp. 206-217). IN: *Proceedings of the 2nd National Conference with International Participation STEM Education and Innovation SMART STEM 2022*. European Institute for Technology, Education and Digitalization, Sofia. ISSN 2738-8387 (printed book); ISSN 2738-859X (e-book)

**2. Ivanova,** K., Karagyozova-Dilkova, D. (2022). Developing 21st century skills through STEAM project-based learning. *Education and technology*, volume 13, issue 1, 213-219. ISSN 1314-1791 (print); ISSN 2535-1214 (online)

**3. Ivanova,** K., Nikolova T. (2023). “Grow, colony, grow!” STEM lesson for 7th grade (p. 155-160). IN: *Compendium of Shared Pedagogical Practices from the Second National School Conference Shared Pedagogical Practices in Science Teaching,* Sofia. ISSN 2683-0744 (print)

4. **Ivanova,** K. (2024). Possibilities for applying mathematical modeling and co-teaching in a STEM lesson in Biology and Health Education (Grade VII).*Pedagogika-Pedagogy*, vol.96, no.1, 118-136

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**5. Ivanova,** K., Karagyozova-Dilkova, D. (2024). Formation of higher level thinking skills through STEM learning in Biology and Health Education (Grade VII). Accepted for publication in *Pedagogika-Pedagogy*, ISSN: 0861–3982 (print), 1314–8540 (online), *Abstracting/Indexing WEB of SCIENCE*

**Other publications of the PhD student**

**Ivanova,** K. (2018). Tools for using chemistry experiment and self-assessment in active learning strategies in Man and Nature. *Chemistry. Natural sciences in education*, 27 (5), 749-758. ISSN 0861-9255 (print); ISSN 1313-8235 (online)

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**Participation in the conference**

1. 2nd National Conference with international participation "SMART STEM Education and Innovation" April 8-10, 2022 Participation with report and publication
2. 14th scientific conference for students and young scientists "Ecology - a way of thinking" May 21, 2022, Plovdiv. Participation with report
3. XIII Scientific and Practical Forum "Innovations in Education and Cognitive Development", August 17-19, 2022, Burgas. Participation with report and publication
4. II National School Conference "Shared pedagogical practices in the teaching of natural sciences" March 24-25, 2023, Sofia. Participation with report and publication

5. Second scientific and practical conference "The Digital Transformation of Education", July 4, 2023, Sofia. Participation with report
6. National Conference "Skills for Innovation in Education" November 24-25, 2023, Sofia

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Notes:

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[3] Recommendation of the Council of the European Union of 22 May 2018 on key competences for lifelong learning: https://eur-lex.europa.eu/legal-content/BG/TXT/HTML/?uri=CELEX:32018H0604(01)&from=EN

[4]https://quincycollege.edu/wp-content/uploads/Anderson-and-Krathwohl_Revised-Blooms-Taxonomy.pdf